An analytical approach to open, cylindrical organ-pipe scaling from a historical perspective with specific reference to the scaling practices of selected organ-builders.

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AN ANALYTICAL APPROACH TO OPEN, CYLINDRICAL ORGAN-PIPE SCALING FROM A HISTORICAL PERSPECTIVE, WITH SPECIFIC REFERENCE TO THE SCALING PRACTICES OF SELECTED ORGAN-BUILDERS.

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ABSTRACT

This thesis considers and analyses scaling methods from the fixed-variable scales of Dom François Bédos de Celles and the constant scales of Georg Andreas Sorge and Johann Gottlob Toepfer to more modern methods. The development of modern scaling is traced, particularly in the light of Albert Schweitzer's ideas on reform in organ-building and the resulting *Orgelbewegung*, with specific reference to the change in scaling practices of English organ-builders before and into the reform. The performance of pipe-length calculations are assessed and a method of determining pipe-scales is proposed in which the scales are designed from the subjective, musical response of an organ-builder to an acoustic analysis. A computer program is given which calculates the dimensions of open, cylindrical organ-pipes in either an eighteenth-or nineteenth-century style.

CONTENTS

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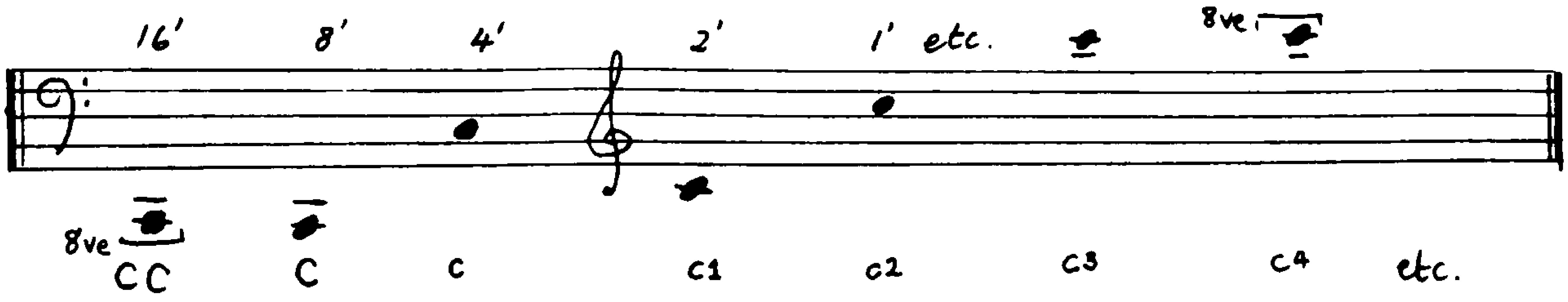
and, of course, Sally.

NOTES

The pitch nomenclature that has been adopted in this thesis is as follows:



This nomenclature is used within the text, except in certain quotations, but when this occurs it is clarified either by an indication of whose pitch nomenclature is being adopted or by the use of square brackets. The information enclosed in such brackets converts pitch nomenclature from a text which may lead to confusion to the system adopted above.

There seems to be no universally accepted grammatical norm for the term organ-builder. This frequently occurs without a hyphen, as organ builder. I have resisted the temptation to correct every author's use of this term to comform to one version. Thus the quotations preserve the original version used by English authors or translators as is appropriate to the context in which they occur. In some cases the term appears as one word *organbuilder*, as in the case of the newly published journal of that name. This has been preserved as well.

All measurements are in millimetres unless specified. Occasionally there are numbers given in centimetres, but these are indicated in the text. All tables appear in millimetres. The use of the inch is only preserved in quotations and its conversion to millimetres appears in square brackets immediately afterwards. The *Pied du Roi* is always converted to millimetres (in some quotations it is given in cm) but the *fuss* is left as such, as there is some doubt as to exactly which *fuss* Sorge referred to. There is a footnote about this at the appropriate point.

Other abbreviations are as follows:

HW	*Hauptwerk*	*Gt.*	*Great Organ*
BW	*Brustwerk*	*Sw.*	*Swell Organ*
RP	*Rückpositiv*	*Ch.*	*Choir Organ*
PED	*Pedals*		

JASA	*The Journal of The Acoustical Society of America*
JBIOS	*The Journal of The British Institite of Organ Studies*
JISO	*The Journal of The International Society of Organ-Builders*
MT	*The Musical Times*
The NGD of MI	*The New Grove Dictionary of Musical Instruments*
The NGD of MM	*The New Grove Dictionary of Music and Musicians*
OLF	*The Organ Literature Foundation*
ORGBLDR	*The Organbuilder*
ORGYBK	*The Organ Yearbook*
OUP	*Oxford University Press*
PM	*The Philosophical Magazine*
PMA	*The Proceedings of The Musical Association*
PR	*The Physical Review*

INTRODUCTION

The most significant recent theoretical (and historical) contribution to the study of the properties and relationships of organ-pipes is *The Calculation of Organ Pipe Scales* by Christhard Mahrenholz' (1900-1980) published in 1938. Nothing further has been published on this topic. Mahrenholz, like the French Benedictine monk Dom François Bédos de Celles (whose work he later republished), was a man of many talents. He was a pastor, with an immense knowedge of canon law, hymnology and was a leading liturgical expert. He was also a mathematician and an authority on Scheidt. This thesis attempts to start where Mahrenholz finished his work, though inevitably a number of the issues are common and are re-examined or reappraised. Mahrenholz's work contains a discussion of sources of scaling methods from Mediaeval times up to Johann Gottlob Toepfer with an analysis of the scales of Dom Bédos. Here, a different approach is taken to Bédos's work, partly in the light of Carl Bleyle's discovery of a new work by Georg Andreas Sorge; *The Secretly kept Art of the scaling of Organ Pipes*. This new approach is also partly as a result of a new analysis of Bédos's scaling method. Although in Germany Richard Rensch has taught the discovery that Bédos's scales are built on the Pythagorean scale, this information does not appear to have been published and, more significantly, no attempt has been made to reduce this to mathematical treatment. To this end a formula to calculate the scales is given in equation 1.9. This is the result of a detailed analysis not of Bédos's scales (*i.e.*, the actual physical dimensions of the pipes) but of his method of drawing a scale chart. Bédos's scales do not follow a geometric series (*i.e.*, the ratio of each term in the series of scale dimensions is constant); they are piecewise, linear scales if they are drawn using baseline *abscissae* which follow a geometric series. However, if they are drawn with a straight line (as Bédos does) they appear with a perturbated baseline.

Inevitably this thesis requires reference to mathematical formulae and the particular terminology of organ-building, specifically of pipe-scales. The measurements and dimensions of a rank of pipes in an organ may be given as the scale - that is, the progression or relationship of the dimensions of one pipe to another. Though other measurements are important, most scales relate pipe-width to pitch (*i.e., pipe-length*). *Three such progressions are common:*

1. *a constant* scale is one in which the progression follows a geometric series.
2. A *fixed-variable* scale is one which is based on a constant proportion whose geometric series is destroyed by, for example, the addition or subtraction of a constant.
3. A *free-variable* scale is one in which the relationship of one pipe to another does not follow a geometric series, is not based on one, and is generally drawn by hand rather than computed.

Mahrenholz divides his discussion of the subject of pipe-scales into two independent parts, namely pipe-length and pipe-width. This thesis is divided into the historical (chapters one and two) and the experimental (chapters three and four). The works of authors such as Bédos, Sorge, and Toepfer (dealt with in chapters one and two) are concerned with pipe-width and do not deal with pipe-length and hence the related question of end-correction. Pipe-length and end-correction have only been dealt with in any detail since the end of the nineteenth-century, notoriously by Lord Rayleigh, but more recently by Ingerslev and Frobenius. Mahrenholz's division of his discussion into pipe-length and pipe-width is a convenient but superficial one. Pipe-length is dependent upon pipe-width although the relationship is complex; diameter, end-correction, mouth-correction and the ratio of mouth-width to diameter confuse the issue enormously. At the present time the mathematical modelling of pipe-dimensions, pipe-speech and pipe-sound through Fourier analysis is exceptionally difficult despite the early attempts by Sundberg. My experiments which test the Ingerslev and Frobenius mouth-correction equation (3.9, page 143) demonstrate that the equation only holds true within a fairly narrow band of pipe-widths. Calculation of length for such narrow-scale pipes as those imitating string tone (where the beard interrupts the jet flow from the flue), and wide-scale pipes such as Blockflutes (where the ratio of the mouth-width to the diameter is less than 1:4) lie just outside the bounds of reasonable accuracy. Solutions to such problems probably lie as a derivative of the field of elliptic functions rather than one which can be solved by the organ-builder in his workshop.

It should be made clear that the tone of an organ is controlled by an almost fantastic array of variables, from the way in which the wind is raised through voicing and proximity of pipes (the effect of which was recognised by Bédos), to the design of the case in which the instrument stands. Two pipes of identical scale, materials, cut-up, foot-hole and wind-way, voiced on the same wind-pressure can be made to sound quite different by what appears to be almost imperceptible variations in other aspects of voicing such as the absence or presence of nicking, position of and small movements of the languid, lower lip, upper lip and the angle at which the laminar jet flow from the flue is impinged upon it allied to the shape of the leading edge. Other factors such as the bevel and angle of the languid, proximity of adjacent pipes, resonance-absorption of the instrument itself and above all, the acoustic environment in which the organ speaks all alter the sound made by the pipes. Examples of such changes are the choked sounds of the so-called 'neo-classical' organ in Britain of the 1950s, 60s and early 70s, due not so much to the pipe-sound as the action type. The explosive nature of the release of air into the pipe from an electro-pneumatic action yields a violent transient region in the wave form. Similarly, the abruptness of these action types stops a pipe's speech dead in a way that a mechanical action will not; thus, new voicing procedures were developed to match new developments in action making. Even if the dimensions of a pipe are copied, all the conditions for it must be copied as well for the reproduction of authentic pipe-sound. The copying of parts of instruments and the synthesis of old and new into a cohesive organ breed without taking notice of other factors (as still happens) is as artistically satisfying as low-grade pseudo-Georgian reproduction furniture. It is a curious state of affairs when British organ-builders design organs primarily suited to the performance of Baroque organ music, particularly that of J.S. Bach, without using electrical registration aids, but incorporating pipe-scales derived from the nineteenth-century or designed following a logarithmic series. Klotz's words ring loud and clear:

> 'Mahrenholz always warned us, those who love the organ, of the dangers of historical dogmatism, indifference and compromise. His goal was *the New Organ*. We would do well to follow his warning and seek his goal'.[2]

What is the point of this discourse? It is simply this: there is something intrinsically important about the right pipe-scale. Other factors do make a pipe sound different (within a narrow band margin of tone, but enough for the musician to discriminate) but none so much as the conception of pipe-scale, for from this measure the dimensions of the mouth are born. It is from this premise that this thesis develops: that the conception of pipe-scale and its calculation is the singularly unique factor in the ultimate determinant of pipe-sound.

The works of so-called theorists and practising organ-builders are discussed, although the division into theoretical and practical is a result of the way in which we see organ-building today rather than the way in which our forefathers saw the task. If the organ that we play develops a fault, we call for the builders. Bédos tells the reader of *L'Art du Facteur d'Orgues* how to correct faults. He was a master of the practical as well as the theoretical; a practising organ-builder as well as a mathematician (testimony to which fact is left to us in his treatise on sundials). By contrast, later writers tended to be players, mathematicians or engineers rather than builders. Sorge was a theorist, but first and foremost a practising organist and composer, being appointed court and civic organist at Lobenstein in 1722 at the age of nineteen. His interest in the theoretical aspect of pipe-scaling only developed in later years. Similarly, Toepfer was a composer, schoolmaster and city organist of Weimar. His interest in the technical aspect of organ design developed through the deterioration of the organ in the Herder church and his acquaintance with the Schulze firm who rebuilt the instrument. Toepfer's influence in organ-building has been enormous, even down to the tools of the trade which he designed and which Walcker's made. Only builders like Cavaillé-Coll were gifted in mathematics and physics. Cavaillé-Coll believed that Toepfer's works were not supported by adequate experimentation, but the firms of Schulze and Walcker were sufficiently convinced by Toepfer to produce their organs almost entirely according to his methods. It is interesting that technical books were written by such authors, not from a theoretical standpoint as we wrongly assume, but from a knowledgeable, practical vantage point. Such a technical train of thought runs through from the work of Mersenne to that of Frobenius, be they practical or theoretical.

Chapter one deals with the historical background: the scaling methods of Bédos, Sorge and Toepfer; the methods of Robertson, Audsley, Clarke and Dixon, (mostly derived from Toepfer) are discussed in less detail. Toepfer and Schulze embraced the *Simplifikationssystem* of Abbé Vogler. The influence of Vogler's acoustical notions on Toepfer is traced.

Chapter two attempts to outline the awareness of the Alsatian Organ Reform and the succeeding *Orgelbewegung*, to the problem of scaling and the development of graphic analysis of it. The idol of the latter movement was Arp Schnitger (p.71); the discussion relating to Schnitger outlines one of the pitfalls of the copying of scales using only the octave c values, thus forming a bogus 'Schnitger' scale which follows fixed-variable principles, rather than the free-variable scales used by Schnitger. Cavaillé-Coll (p.83) used some scales by Bédos and some by Toepfer, and represents the growing technological awareness of the nineteenth-century, as a child of the new age (p.84). His association with Toepfer is outlined at this point. The firm of Schulze represents the total adoption of Toepfer's methodologies and, more significantly, the transmission of these ideas to the English organ-building scene through Edmund Schulze. With the influence of both the Schulze and Walcker firms (p.97), on such companies as Willis (p.99), Wilkinson (p.101), J.J.Binns (p.104), Harrison and Harrison (p.106) and Lewis (p.111), all of whom copied or adapted their scales, British organ-building entered a new era. In some cases (*e.g.*, J.J. Binns), the true nature of Toepfer's constant scale was not discerned until the 1920's, almost a century after Toepfer had proposed it in *Die Orgelbaukunst* of 1833. Some organ-builders today still cling to their 'art', defending it vehemently as 'craft', 'tradition', or secret information passed from generation to generation, when in fact it is little more than the long-continued habit of using Toepfer's scales (and nineteenth-century methods) without ever having understood the notion of a constant scale.

A discussion of the results of the transformation of the British organ-building scene, through continental influence, follows the specific references to individual organ-builder's scaling practices before the effect of the *Orgelbewegung* (p.121) took root in this country in the 1950s (p.123) with the

Royal Festival Hall organ. Fixed-variable and free-variable scales almost found favour, although only in the 1980s has any distillation of these features taken place (*e.g.*, St. David's Hall, Cardiff, Peter Collins, 1982).

Chapters three and four move from the historical to the experimental part of the thesis. Chapter three deals with the development of mouth-correction from the late 1870s onwards, and the resultant accuracy in calculation of pipe-length is tested with practical experiments. These experiments test Ingerslev and Frobenius' pipe-length equation where the relationship of the mouth-width to diameter changes as do the dimensions of the mouths of the pipes. A new type of experiment was devised to see how sound reacted over time in the church of St. Oswald in Durham City. The acoustical data collected from the experiment was plotted in three dimensions - time, decibel decay and frequency. This gave an 'acoustic landscape' of the church which enabled the acoustic quirks of the building to be seen in great detail.

Some of the philosophical problems of modern organ design are dealt with, leading directly to a set of criteria for design of pipe-scale (p.155-163) before the application of computer analysis and development of suitable scales in chapter four. The flow-chart for the computer program is given on pages 207 and 208. The program calculates the dimensions of a single organ-pipe or a series of organ-pipes in either an eighteenth- or nineteenth-century style. It requires certain information to begin: temperature, diameter and frequency of a reference pipe and the details of mouth dimensions. The mouth dimensions may be altered for every pipe in the series. The output of the program may be seen in appendices E and F.

Sadly, the necessity to complete the thesis prevented further collaboration in a project at St. Oswald's church in Durham. This has forced the author back on a subjective conclusion, although an objective analysis of the finished product could have been of profound significance. It is, however, this writer's belief that, despite the advantages of scaling in an eighteenth- or nineteenth-century manner by computer, the governing ingredient in this long established and ancient art of organ-building must always be subjective taste. As such, this is duty bound to change from generation to generation, as taste changes. The computer must aid the industrial process rather than governing it. The quest in organology must be to ask why an organ-builder worked in a particular way rather than to simply copy what he did without understanding his intentions or methods. Organ-building may be primarily an art and a science in subordination, but nevertheless it is both, as many generations of inquisitive organ-builders bear testimony.

Inevitably a thesis has to be restricted. Further research in this area might obviously be extended to the scaling of reeds, although much more of the historical evidence has been destroyed in the process of revoicing reed pipes than it has with flues. Moreover, reed pipes tend to deteriorate much more quickly than flue pipes. The vexed question of mixture composition and breaks has not been tackled in this present study. Mixtures vary so much that a vast amount of field work would need to be done to begin to gather accurate information not only about composition and breaks but scaling as well. Discrimination of methodologies of scaling is much more difficult to establish with old cone-tuned pipes and the problems of constructing pipes of less than 4mm diameter means that trebles are often of the same diameter. The effect of a mixture is more inherent in its composition and arrangement of breaks than of its scale. On the mathematical side of scaling, exactly how early English builders scaled their pipes is yet to be revealed. Despite the fact that recent publications list scales by such builders, analysis of them suffers from viewing them only in the light of being part of a geometric series or as a derivative of such as series (e.g., by the use of an addition constant). Evidence drawn from Bédos's text points to the probable use of the Pythagorean scale owing to the ease by which it may be drawn by dividing the *abscissae* by 4 and 5 to obtain all the semitone divisions.

CHAPTER ONE

THE SCALING METHODS OF DOM FRANÇOIS BÉDOS DE CELLES, GEORG ANDREAS SORGE AND JOHANN GOTTLOB TOEPFER

Dom François Dom Bédos de Celles (1705-1779), in his treatise *L'Art du Facteur d'Orgues*[1], for the first time in organ-building literature, sets out at great length the exact measurements, allied with scale-charts, for the construction of organ-pipes. Dom Bédos declares in the introduction to Part 1:

> 'No craft is without a theoretical basis. No craftsman should be ignorant of the principles of his speciality. Organ-building has its theoretical basis, as do all other crafts. The organ-builder must be aware of this, in order to avoid the risk of working blindly at the construction of such a considerable instrument, whose cost is always high. Part of the knowledge he must have is preliminary, and although it does not so directly concern his craft as does specialised knowledge, it is no less indispensable to him. He must know at least the fundamental rules of mechanics, statics, and cabinet-making, and the tools peculiar to his kind of work. One of his chief aims is to know all the various pipes and registers of the organ, and to be able to scale them, *i.e.*, to give them the correct dimensions and proportions. Finally, he must know the various elements which make up the organ, and how the whole instrument functions. This is a summary of the knowledge required of an organ-builder.'[2]

Dom Bédos represents that breed of intellect, well versed in arts and sciences, which has been replaced with the highly specialised knowledge of the academic. Dom Bédos, a Benedictine in the order at Saint-Maur near Toulouse and subsequently at the Abbey of Saint-Croix in Bordeaux (1745-1748), was a master of both the theoretical and the practical. He published a treatise on sundials and their design, *La Gnomonique practique*, in 1760; he wrote *L'Art du Facteur d'Orgues* (completed in 1778, one year before his death) after opening a workshop at the Abbey of Saint-Denis, to the north of Paris in 1762. Charles Ferguson[3] writes

> 'The dates at which the various parts of *L'Art du Facteur d'Orgues* were published reflect the author's painstaking work, reminding us of the French adage whereby a long, meticulous labour is "a Benedictine's task". Part I appeared in 1766, containing general information on geometry, mechanics, and tools, and giving descriptions and dimensions for every part of the organ. Part II was published four years later in 1770, giving detailed instructions for making all the parts...as well as for the voicing and tuning, enlarging, and maintaining the finished instrument. Part III also dates from 1770, containing models of stop lists and a specimen contract for having an organ built. It also explains how to test an organ, advises organists on matters within their competence concerning the building and maintaining of an organ and recommends certain registrations as being appropriate to various kinds of compositions.'

The final part (Part IV) was contributed by an Augustinian, Father Marie-Dominique-Joseph Engramelle. This latter part deals with the procedure for recording music on barrels for mechanical performance.

The measurements in Dom Bédos's work are in the duodecimal *Pied du Roi*. The *Pied du Roi* was divided into 12 *pouces*, each *pouce* into 12 *lignes*, and each *ligne* into 12 *points*. This *Pied* was slightly longer than the Imperial foot, being 32.48cm compared with 30.48cm for the latter. Dom Bédos defines a scale in the following way:

> '206. Scale is used to indicate the progression or series of tones in the octave or scale. Scales, in organ-building, contain measurements and dimensions for each pipe; rather these measurements and dimensions are themselves the

scales. Each stop has its own peculiar scale, and the scale makes it possible to give each pipe its correct proportions.'[4]

Dom Bédos is quite forthright about the use of 'geometry' to calculate the dimensions of the pipes

'so precisely that once they are voiced and installed they will be in tune.'[5]

The reasoning behind a practical implementation of such ideas is outlined as follows:

'The thickness of the metal would have to be carefully graduated, the pipes would have to be perfectly cylindrical and the height of the mouths and the thickness of the languids would have to be carefully graduated, for these factors influence the speech of the pipes to a considerable degree. Again, the careful graduation of toe-holes and windways would have to be followed.'[6]

Dom Bédos argues that the application of these factors would 'leave no tolerance' for the final regulation and imparting of speech to pipes, and as the correct tone would need to be induced from each pipe, adjustment of precise calculations would alter the tuning of a pipe. Dom Bédos was obviously keenly aware of the effect of the proximity of pipes to each other and its resultant manifestation in the alteration of stability of tuning. He continues,

'..assuming that complete geometrical precision were not possible, but carefully followed in making the pipes, each pipe would have to be at least one *pied* away from every pipe and any other obstacle.'[7]

It is difficult to know at whom, if anybody, Dom Bédos is jibing. It is possible that Bédos is commenting on the whole tribe of Teutonic mathematician-composers and theorists like Marpurg, Mattheson and Mizler. Georg Andreas Sorge (1703-1778) had written his own treatise *The Secretly Kept*

Art of the Scaling of Organ Pipes in 1764, two years before Dom Bédos published part I (1766) and six years before he published Part II. It is possible that Dom Bédos knew of, and perhaps disapproved of, Sorge's theory of logarithmic scaling and chose to emphasise that, in this so-called 'Art', empirical methods were the best ones.

> '208. Accordingly, in the empirical method of scaling as I am about to explain it, the diameters of the pipes will be found not to progress according to geometrical rules. For example, a pipe which is to sound the octave above another ought to be not only half as long, but half as great in diameter. If this rule were followed concerning the diameter, the organ would have a poor tone, particularly in the treble. Experience has shown that this proportion must be altered according to the function of the various stops and the tone they are to have. Therefore, I shall adhere to methods which long experience has shown to be the best, as the best builders ordinarily use them.'[8]

An exciting comparison may be made with the opening of Sorge's text:

> '...it will not be practical to determine the ratio of the octave the same as [it is determined] on a string with [the ratio] 1:2, for then one would obtain colossal tankards in the 16- and 32-foot octaves. even though the smallest pipe were made so narrow that a large pin head scarcely could be inserted into it. Therefore we must look for another ratio for the circumference, and consequently, also for the length.'[9]

which is his *defensio* for a proposition to calculate the intervening semitones between whichever halving ratio for the octaves is used. It is difficult to imagine why Dom Bédos was not concerned with other methods of pipe-calculation, since he is concerned with almost every other aspect of organ-design and in his own words:

> 'We have attempted to omit none of this immense but necessary detail in this chapter.'[10]

It seems more likely that Bédos considered the use of geometry to calculate pipe-scales to be an infringement on the part of science and an intrusion of it into one of the most hallowed arts and craft industries.

The ingredients of a pipe-scale are the length and diameter. It is interesting to compare Bédos and Sorge over the matter of a division of a scale into semitones. Sorge writes:

> 'An accurate scale is the most important part of the profession of organ-building. If one could proceed with the measurements of pipes as he does with a string on the monochord, where a doubled length gives an descending octave, then it would be an easy matter to calculate and measure out the correct circumference and length, width and height of the mouth, etc., of every pipe; for then one could make the largest [pipe] of the Principal exactly 32 feet in length, and then proceed further with the circumferences proportionately, and compute and measure out the intervening tones according to the numerous temperaments already at hand.'[11]

and Bédos:

> '212. The half-steps....are not at all equal. Temperament is what determines the differences, as I shall explain in Part II. in connection with tuning. There would be no advantage in adhering to those small differences in interval when scaling pipes, for the reasons set forth in 207, so we shall follow the easiest and simplest method.'[12]

Clearly Bédos and Sorge do not agree over this, not small, matter of temperament, relative to scaling.

Dom Bédos discusses in considerable detail the 'division of a scale'. The table is reproduced below, showing the 'procedure for deriving the length of each pipe in one octave, used in drawing scales',[13] in which the fourth ratio is 3:4 and the fifth ratio is 2:3.

Reference Note	Proportion taken	Resulting interval	Resulting note
C (given)	3/4	Fourth above	F
C	2/3	Fifth above	G
G	4/3	Fourth below	D
D	2/3	Fifth above	A
A	4/3	Fourth below	E
E	2/3	Fifth above	B
F	3/4	Fourth above	A#
A#	3/2	Fifth below	D#
D#	3/4	Fourth above	G#
G#	3/2	Fifth below	C#
C#	3/4	Fourth above	F#

The 'division of a scale' is also given in a text as follows (the ratios to C13 in square brackets are mine):

> ' Draw a straight line, X1 (see fig. 1), and divide it exactly in the middle at 13. This will give one octave higher than distance X1 because it is half as great [1/2].
> Divide distance X13 into four equal parts, and transfer three of these parts from X to 18. This will give F at 18, a fourth above C, at 13 [4/3].
> Divide distance X13 into three equal parts, and transfer two of them from X to 20. This will give G at 20, a fifth above C, at 13 [3/2].
> Divide distance X20 into three equal parts, and transfer one of these parts from 20 to 15. This will give D at 15, a fourth lower than G, at 20 [9/8].
> Divide distance X15 into three equal parts, and transfer two parts from X to 22. This will give A at 22, a fifth above D, at 15 [27/16].
> Divide distance X22 into three equal parts, and transfer one from 22 to 17, obtaining E17, a fourth below A [81/64].
> Divide distance X17 into three equal parts, and transfer two from X to 24, obtaining the fifth, B, at 24 [243/128]. So much for the Diatonic scale. Now we shall find the five remaining steps needed to make a Chromatic scale.
> Divide distance X18 into four equal parts, and transfer three from X to 23. This will give A# at 23, a fourth above E [16/9].
> Divide distance X23 in half, and transfer one half from 23 to 16, obtaining a fifth below, or D#, at 16 [32/27].
> Divide distance X16 into four equal parts, and transfer three from X to 21. obtaining a fourth above, or G#, at 21 [128/81].
> Divide distance X21 in half, and transfer one half from 21 to 14, obtaining a fifth below, or C#, at 14 [256/243].
> Divide distance X14 into four equal parts, and transfer three from X to 19, obtaining a fourth above, or F#, at 19 [1024/729].'[14]

Dom Bédos's 'division of a scale'

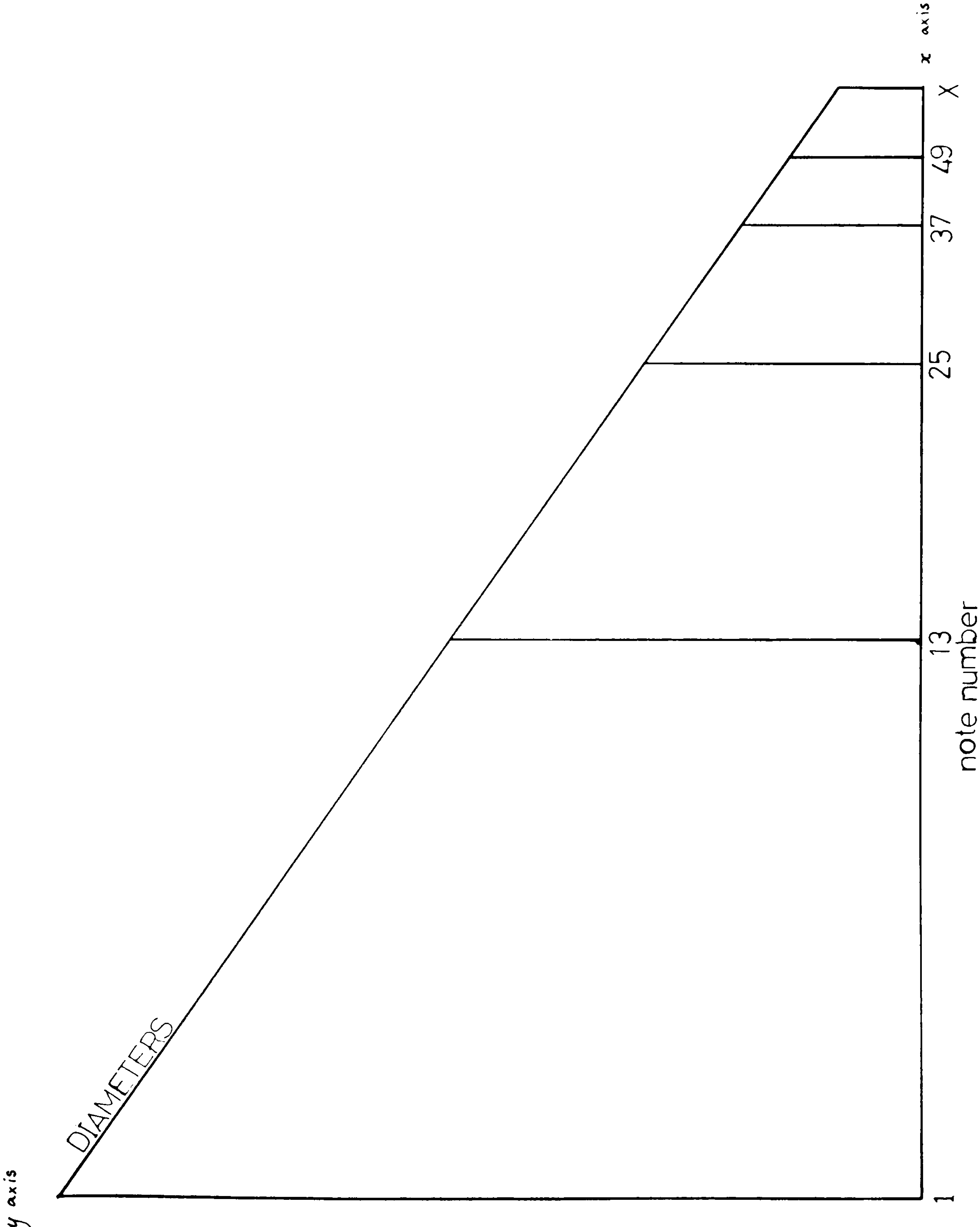


Fig. 1

Using the following equation to convert intervals in ratio form into cents

$$C = 3986.314 \log_{10} \frac{f_1}{f_2} \qquad 1.1$$

where C is the interval in cents, and
f_1 and f_2 are frequencies between the notes

we obtain

NOTE	RATIO	DECIMAL	INTERVAL IN CENTS
C	2/1	2	1200.00
B	243/128	1.8984	1109.775
A#	16/9	1.77	996.090
A	27/16	1.6875	905.865
G#	128/81	1.5802	792.180
G	3/2	1.5	701.955
F#	1024/729	1.4047	588.270
F	4/3	1.33	498.045
E	81/64	1.2656	407.820
D#	32/27	1.1852	294.134
D	9/8	1.125	203.910
C#	256/243	1.0534	90.225
C	1	1	0

Which is, owing to its dependence upon a succession of pure fourths and fifths, the Pythagorean scale. Bédos was certainly aware that this length scale was in need of refinement (see item 212, quoted on page 13) but for simplicity in the laying out of the scales he adheres to this 'simplest method'.

These pipe lengths are measured from X (see fig. 1) to which ever pipe number is required, the diameters of which are determined as follows

> '...a single line will give every one. Only the diameters of the first and last steps need be known.'[15]

The diameter of the lowest note (C) of a *Doublette* is given by Bédos as 2 *pouces*, 1,1/2 *lignes* (57.52 cm), the highest C (c5) as 3 *lignes*, 9 *points* (8.46 cm). The corresponding circumferences are given as 6 *pouces*, 8 *lignes* (180.47 cm)

Diapason du Prestant et du 8 pieds ouvert.

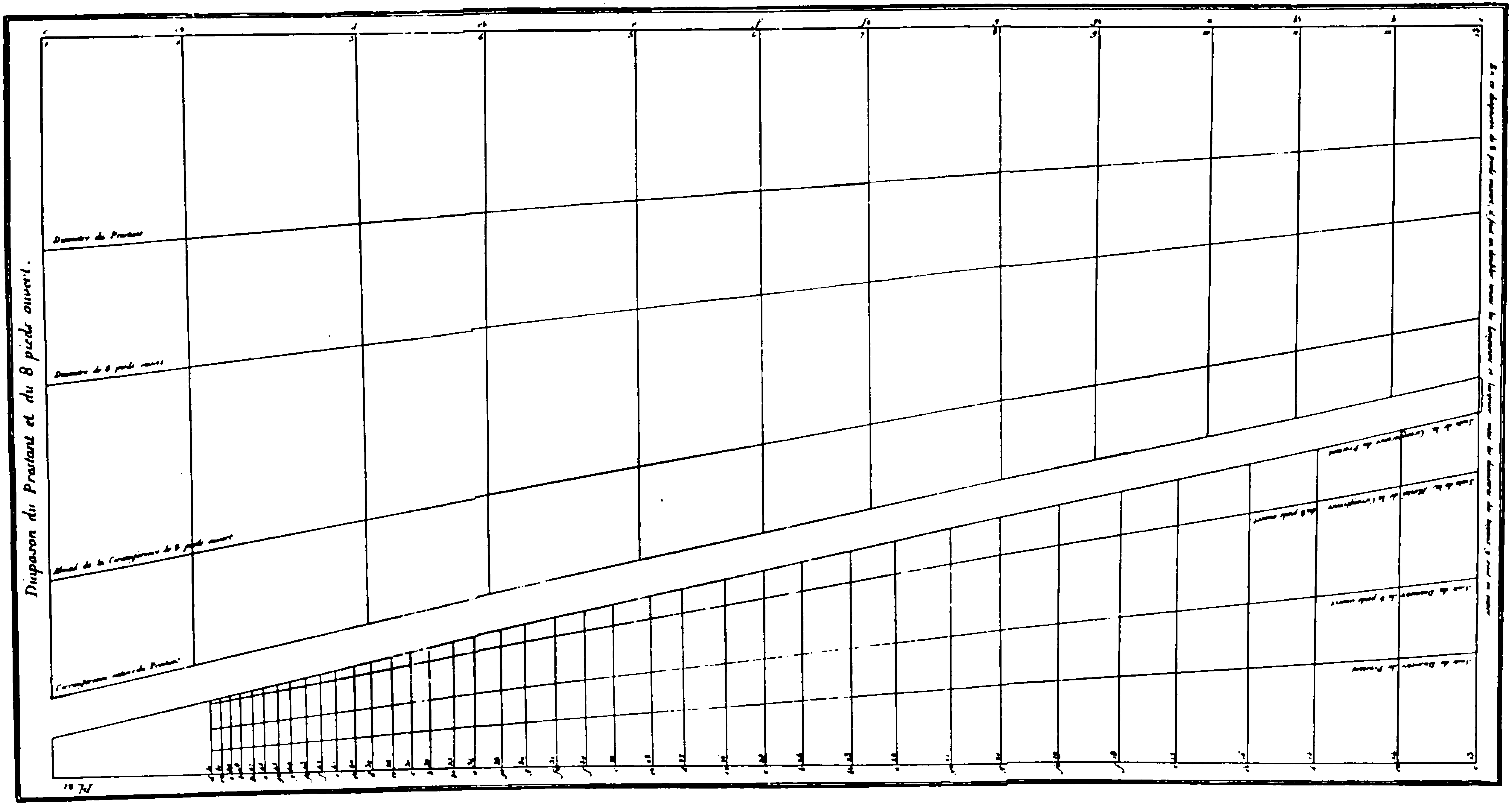


Fig. 2

and 11 *lignes*, 9 *points* (26.51 cm). These measurements for the two C pipe circumferences are set on the length-chart (Fig. 1) and perpendiculars dropped at the respective notes for the correct length and the two points joined. By this process all intervening semitones are given diameters easily read off from the chart. Figure 2 shows the whole scale for an *Ouvert* 8′, as drawn by Dom Bédos. The diameter of the lowest note (C) is given as 5 *pouces*, 9 *lignes* (155.65mm) the circumference being 1 *pied* 6 *pouces*. The highest note, c3, has a diameter of 9 1/2 *lignes* (21.43mm) and a circumference of 2 1/2 *pouces* (67.67mm). This chart is not reproduced to scale.

Bédos gives the lengths of pipes in the first octave of a 4-foot stop.[16]

NOTE	*PIEDS*	*POUCES*	*LIGNES*	*POINTS*	CM
C	4	-	-	-	129.94
C	3	9	6	9	123.34
D	3	6	8	-	115.50
D#	3	4	6	-	109.63
E	3	1	11	1	102.66
F	3	-	-	-	97.45
F#	2	10	2	-	92.49
G	2	8	-	-	86.63
G#	2	6	4	6	82.23
A	2	4	5	4	77.00
A#	2	3	-	-	73.09
B	2	1	3	4	68.43
C	2	-	-	-	64.97

Figure 3 shows a plot of these pipe lengths which are obviously culled from experience. Dom Bédos does not give further details of the stop to which these lengths belong which must be an oversight since he himself points out

> 'Notice that scale of pipes varies according to their pitch and the effect that they are to produce.'[17]

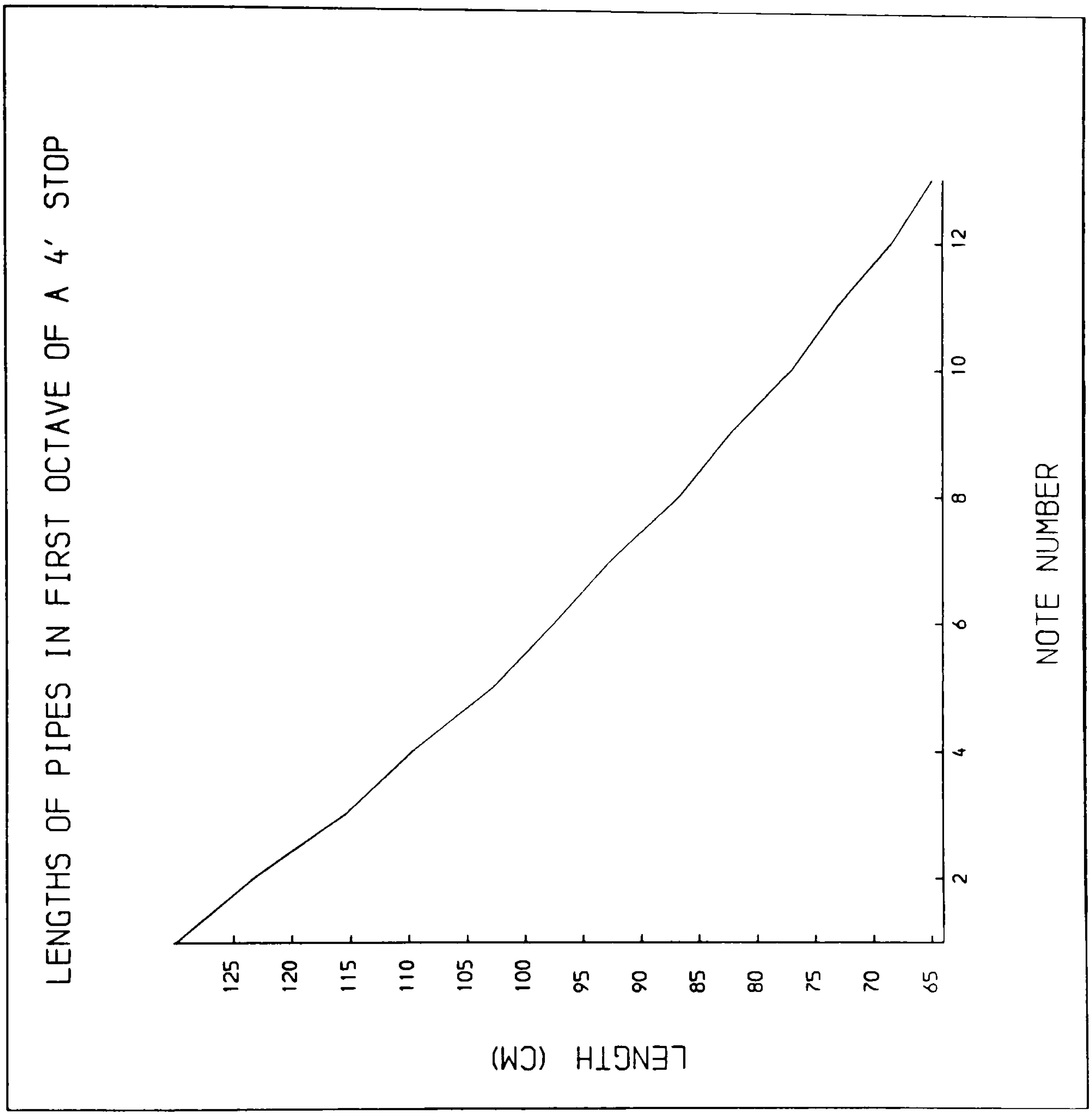

LENGTHS OF PIPES IN FIRST OCTAVE OF A 4' STOP
LENGTH (CM)
125
120
115
110
105
100
95
90
85
80
75
70
65
NOTE NUMBER
2
4
6
8
10
12

Fig. 3

He must also have been aware of the converse, that the pitch of a pipe varies according to its scale.

From the information contained in Bédos's method of linear scaling and the pipe-lengths given in the table above, it is possible to express calculation of the diameters as

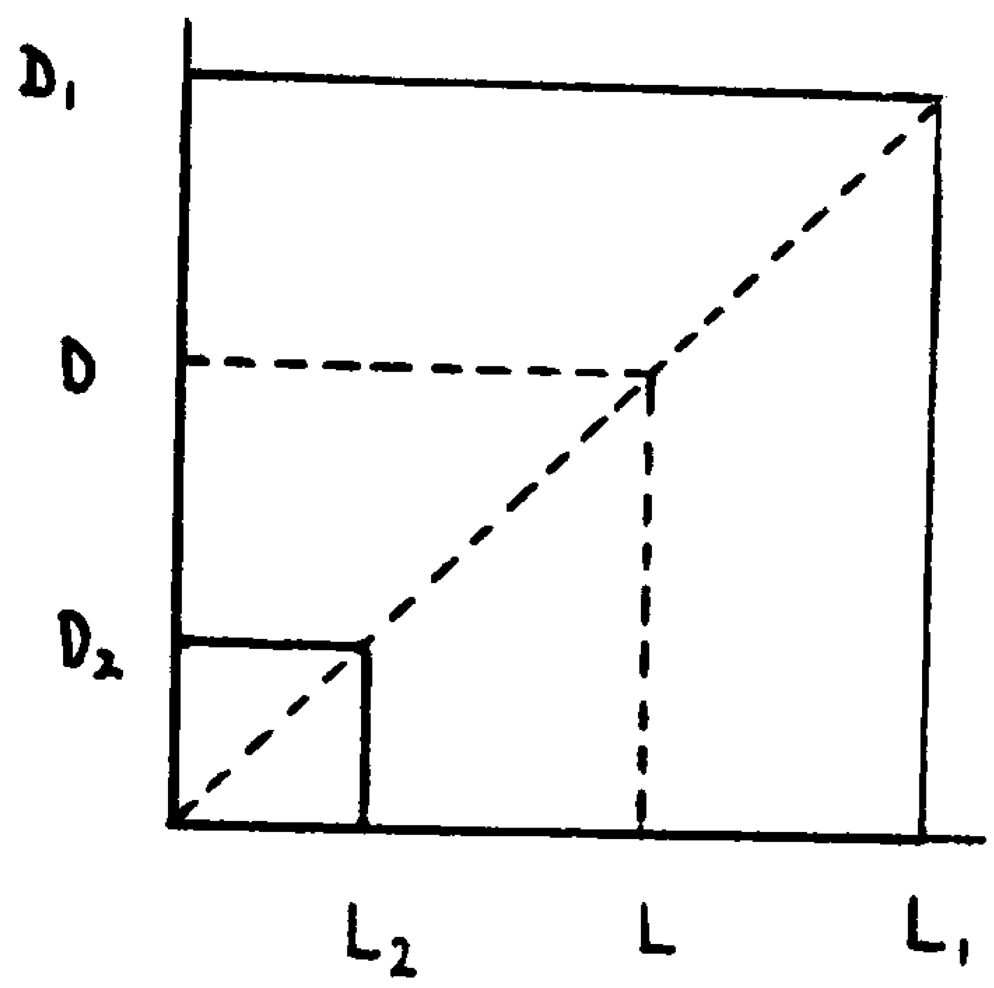


Fig. 4

$$D = D_2 + (D_1 - D_2) \times \frac{(L - L_1)}{(L_1 - L_2)} \qquad 1.2$$

where

the longest pipe has a length L_1 and a diameter D_1
the shortest pipe has a length L_2 and a diameter D_2
the intermediate pipe has a length L and a diameter D.

This equation (1.2) will not satisfy the requirement of the organ-builder in determining pipe-lengths, as the data for the base line must be known. The data for L, L_1 and L_2 must be *actual* measurements from the length of the chart. The ordinates on the base line of the Bédos charts are perturbated by the Pythagorean scale; these abscissae are not equally spaced, although the distances between the abscissae (in general) decrease in size, albeit an irregular decrease. The scale charts of Dom Bédos *look* linear, but if the charts are redrawn, as in figure 5, with the base line

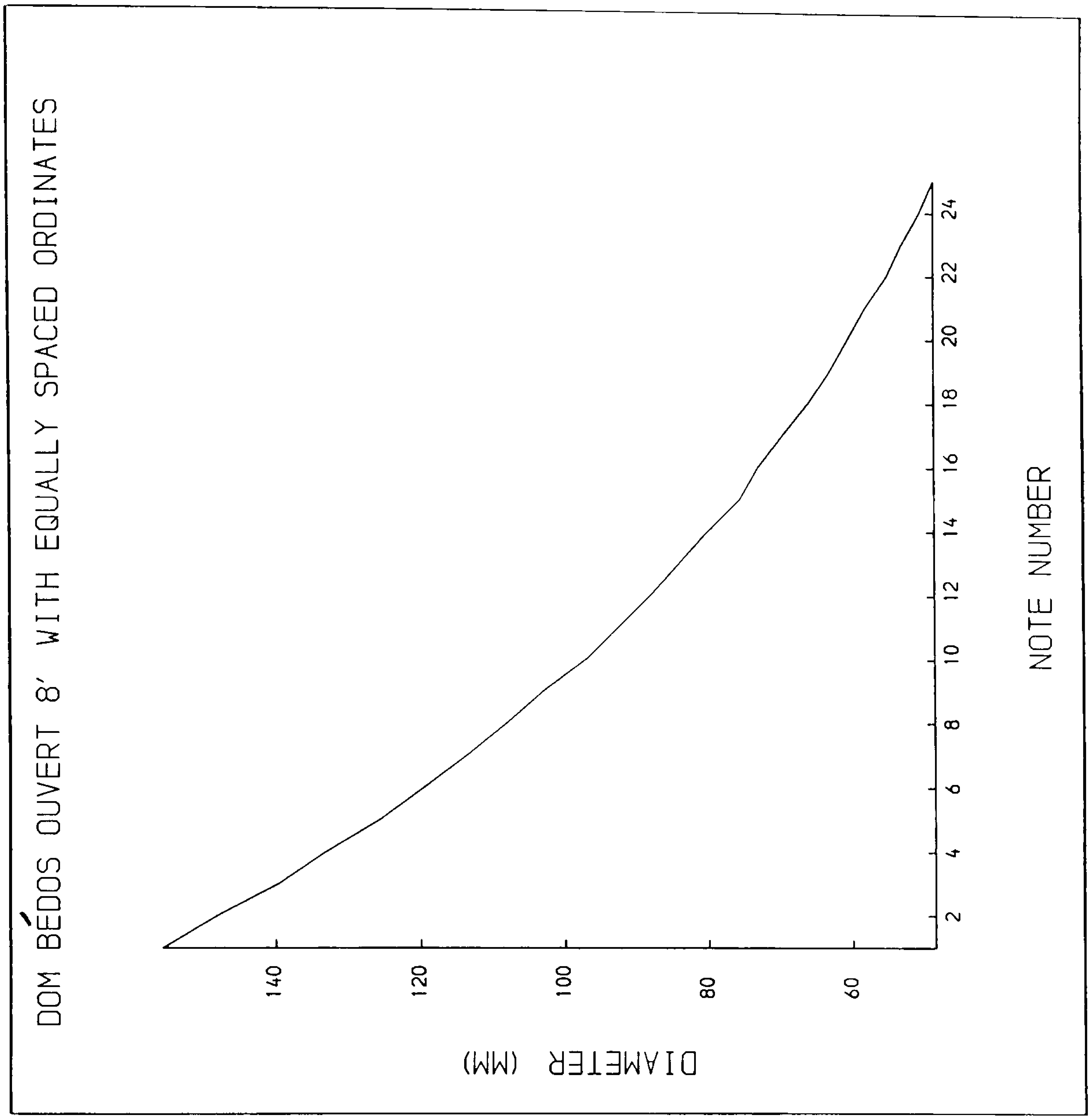

DOM BÉDOS OUVERT 8′ WITH EQUALLY SPACED ORDINATES
DIAMETER (MM)
140
120
100
80
60
2
4
6
8
10
12
14
16
18
20
22
24
NOTE NUMBER

Fig. 5

represented by equally spaced ordinates, then the scale appears as a piecewise, linear scale.

The gradient of the line in Bédos's charts may be expressed as

$$Y = MX + C \qquad 1.3$$

where M and C are constants for each scale graph; X and Y are the horizontal and vertical axes of a graph.

In order to obtain a formula for the whole range of possible diameters, it is better to renumber the abscissae (which correspond to note numbers in Dom Bédos's charts, C1, d51 etc.) as starting from 0 rather than 1. In this way the base line represents, for convenience, *step numbers*; the octave corresponding to C=0, c=12, c1=24 etc. The constants may be calculated from

$$C = Y_0 \qquad 1.4$$

and from 1.3, M may be calculated from

$$M = \frac{Y_{12} - C}{X_{12}} \qquad 1.5$$

where $X_{12} = L/2$ (as described in Bedos's text for the drawing of each chart) and L is the total length of the chart and as such, the length of the lowest pipe in millimetres. Y_{12} is the ordinate for the diameter corresponding to length X_{12}. If the diameter corresponding to L were known, it could be denoted by Y_{∞}, such that

$$Y_{\infty} = ML + C \qquad 1.6$$

and thus

$$M = \frac{Y_{\infty} - C}{L} \qquad 1.7$$

Supposing that M, C and L are known, together with a set of ratios (corresponding to the Pythagorean scale), each ratio being the relationship of each semitone to the lowest note of each scale, (C) denoted by $S_0, S_1, \ldots S_{11}, S_{12}$, the data for the Pythagorean scale being given as

$$\begin{array}{ccccccccccccc} C & C\# & D & D\# & E & F & F\# & G & G\# & A & A\# & B & C \\ 1 & \frac{256}{243} & \frac{9}{8} & \frac{32}{27} & \frac{81}{64} & \frac{4}{3} & \frac{1024}{729} & \frac{3}{2} & \frac{128}{81} & \frac{27}{16} & \frac{16}{9} & \frac{243}{128} & 2 \end{array}$$

the diameter corresponding to n, Y_n, where

$$n = 12k + r , \quad 0 \leqslant r \leqslant 11. \qquad 1.8$$

k representing an index for each octave unit of the charts, such that k_0 is the first octave and k_1 the second octave, etc.,

the formula for Y_n is given as

$$Y_n = M \left\{ 1 - \frac{1}{2^k} \quad \frac{1}{S_r} \right\} L + C \qquad 1.9$$

where S_r is the ratio corresponding to Y_n.

Georg Andreas Sorge

Sorge's *Secretly kept art of the Scaling of organ pipes - Die geheim gehaltene Kunst von Mensuration von Orgel-Pfeiffen*[18] - was probably as much a secret in view of the fact that he published most of his compositions and treatises at his own expense and that he needed to live on the proceeds of his work, as that the organ-building craft considered it so. The advertisement for this work first appeared for sale in *....zuverlaessige Anweisung Claviere und orgeln behörig zu temperiren und zu stimmen* (1788)[19] and two years later in his *Compendium*[20], Sorge wrote:

> 'Friends of the organ-building profession, I hereby give notice that I have completed in manuscript *Die geheim gehaltene Kunst der Mensuration.* Master organ-builders will hardly give us any information about this subject, for they consider this craft a secret one. But it is proper for an organist and building inspector to understand such. I am ready to have it printed only if I can do so without a loss.'[21]

There are two extant copies of this work which evidently never sold well. Sorge informs us in '*Anweisung zur Rational-Rechnung* (Lobenstein, 1749)[22] that he only learned logarithmic arithmetic in his 46th year at the instigation of Meckenheuser's[23] treatise. In 1747, Sorge was invited to become the fifteenth member of the infamous *Societaet der Musicalischen Wissenschaften* which was founded in 1738 by Lorenz Mizler Von Kolof in the same year that Johann Sebastian Bach was invited to become the fourteenth of the *Societaet's* twenty members.

Mizler, a major figure in the history of 18th-century German music and a pupil of Bach from 1731-34, commanded an immense knowledge of music, mathematics, philosophy, law, theology and the Natural Sciences.[24] He held the view that music could not be completely comprehended unless it was supported by mathematics.[25] His philosophical outlook was orientated around the writings of Christian Wolf and Gottfried Liebnitz. Bleyle writes:

> 'Mizler fought throughout his life for the thesis that music could not be completely comprehended unless it was supported by mathematics, and that both music and mathematics then needed to be elevated through the philosophy of Christian Wolf, whose style and procedural techniques were to be followed by the Society's members.'[26]

Because music was concerned with *qualities*, its inherent mathematical knowledge could be united with the philosophic and through such a process the perfection of musical knowledge could be achieved. Mizler and his *Societaet* were severely criticised, not least because of the view that one could compose through calculation, and, as a result, Sorge was at odds with Marpurg for most of his life.

Sorge, then, an advocate of equal temperament became aquainted with logarithmic arithmetic in 1748. He transferred the mode of calculation used by Meckenheuser and Breitfield[27] for dividing the monochord into twelve geometrically equal divisions by the use of logarithms, into a method of calculation of pipe-scales.

> 'Although numerous theoretical works pertaining to the organ, such as those by Adlung, Bendeler, Foerner, Praetorius, Vogler, Werkmeister, etc., exist from this period, none of these writers proceed from mathematical suppositions. Even Dom Bédos' *L'Art du Facteur d'Orgues*, by far the more important work of the period, contains little more than the practical experiences of outstanding French organ builders in addition to specifications, measurements, and scalings of both large and small organs calculated according to conceptions of the time'.[28]

Mahrenholz recognised that Sorge was an important figure in scaling development:

> 'With Georg Andreas Sorge begins a new era of scaling mathematics'.[29]

Sorge's method essentially kept the ancient ratio of 1:2 which would be sufficient a scaling for a limited number of octaves, but not for the entire compass of a stop, for reasons quoted from Sorge earlier (see p. 12). Instead of using the octave for the ratio 1:2 he offers scales halving on the major 9th, and minor and major 10th. The diameter and cross-section of a pipe-scale has always been determined by the octave ratio: Sorge suggests these three methods of scaling of which Mahrenholz (wrongly) takes the 'ninth-scale' as being standard.[30]

The Scales are calculated as follows: Sorge takes a pipe whose circumference is 277 *Scrupel*[31] (sounding c2), half of which is 138.5 *Scrupel* when halving on the major ninth above gives d3. The intervening semitones are found by logarithms as below:

3.4424798 log. to 277.0 (e2)
3.1414498 log. to 138.5 (d3)

0.3010300 difference

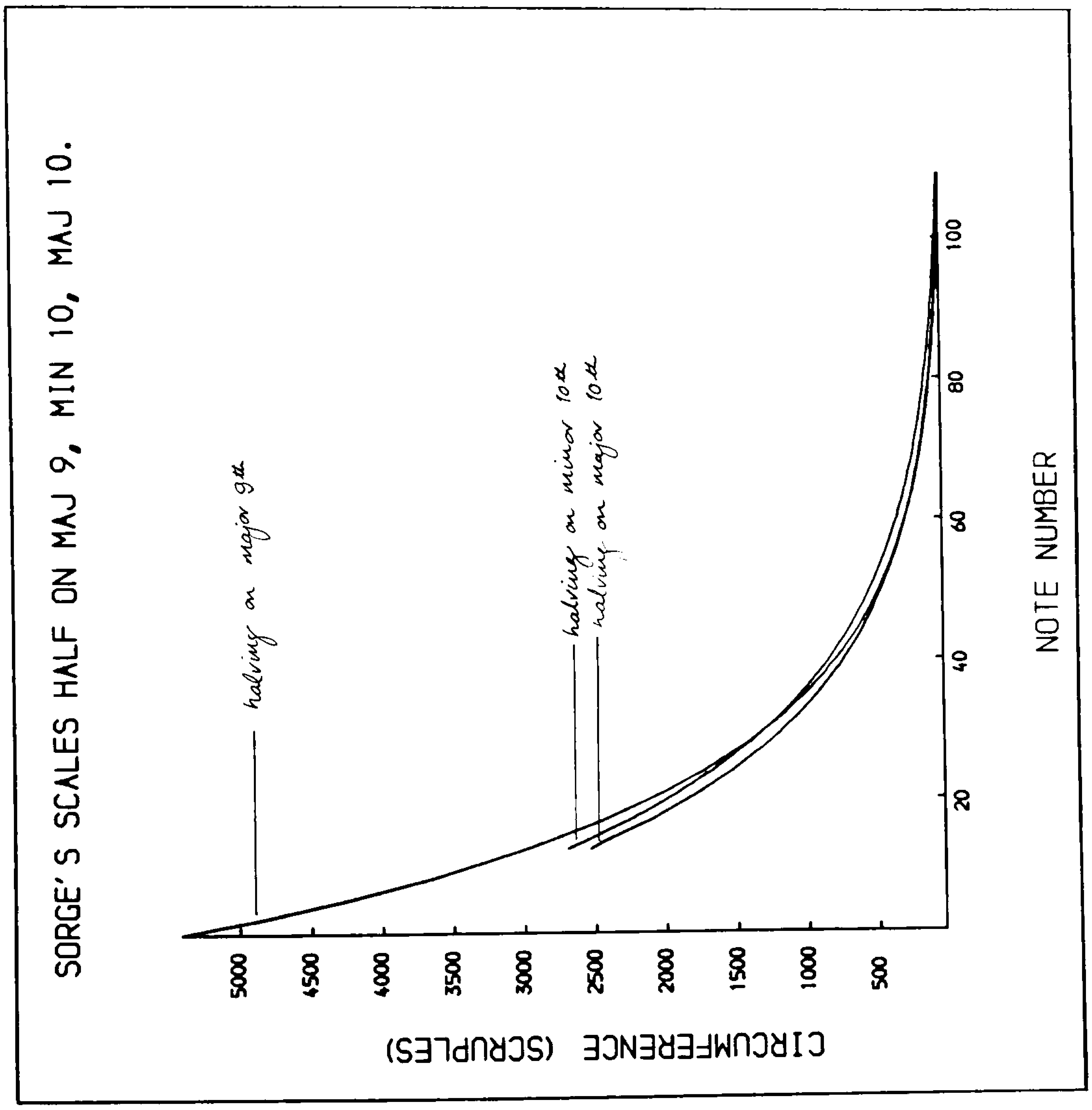
Now we look for the 14th part of 3010300

0.0215021 3/7
14)0.3010300

'If we add this 14th part to the logarithm of d3 the logarithm of c#3 is obtained, whose antilogarithm indicates how large it must be [in circumference]. This operation is repeated as often as necessary until c2, the descending 9th from d3, in reached. Now, because this c2 is the doubled number of d3, it is obvious that by doubling we can proceed downward as far as necessary, and upward, by halving to the smallest pipe. The procedure from d3 to c2 looks like this:

Logarithmic Calculation of the Circumferences from d3 to c2

3.1414498	138.5	d3
215021 3/7		
3.1629519 3/7	145.5	c#3
215021 3/7		
3.1844540 6/7	152.9	c3
215021 3/7		
3.2059562 2/7	160.6	b2
215021 3/7		
3.2274583 5/7	168.8	bb2
215021 3/7		
3.2489605 1/7	177.4	a2
215021 3/7		
3.2704626 4/7	186.4	g#2
215021 3/7		
3.2919648	195.8	g2
215021 3/7		
3.3134669 3/7	205.8	f#2



SORGE'S SCALES HALF ON MAJ 9, MIN 10, MAJ 10.
halving on major 9th
halving on minor 10th
halving on major 10th
CIRCUMFERENCE (SCRUPLES)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
NOTE NUMBER
20
40
60
80
100

Fig. 6

215021 3/7			
3.3349690 6/7		216.2	f2
215021 3/7			
3.3564712 2/7		227.2	e2
215021 3/7			
3.3779733 5/7		238.7	d#2
215021 3/7			
3.3994755 1/7		250.8	d2
215021 3/7			
3.4209776 4/7		263.6	c#2
215021 3/7			
3.4424798		277.0	c2'[32]

The table below is a compilation of Sorge's scales from 32 foot C to 2 foot c. The pitch nomenclature is Sorge's, the numbers in brackets are errors from the same scale given in *Der in der Rechen-und-Messkunst wohlerfahrne Orgelbaumeister*,(1773).[33] These scales are plotted in figure 6.

note	halving on major 9th	halving on minor 10th	halving on major 10th
C2	5401.6	-	-
C#2	5139.2 (5142.4)	-	-
D2	4882.8 (4892.8)	-	-
D#2	4656.0	-	-
E2	4432.0	-	-
F2	4217.6	-	-
F#2	4012.8 (4014.4)	-	-
G2	3810.2 (3820.8)	-	-
G#2	3635.2	-	-
A2	3459.2 (3460.8)	-	-
Bb2	3292.8 (3282.8)	-	-
B	3132.8 (3134.4)	-	-
C1	2982.4	2534.6	2690.88
C#1	2838.4	2434.4	2576.64
D1	2700.8	2321.6	2467.52
D#1	2569.6 (2571.2)	2216.0	2362.88
E1	2446.4	2116.0	2262.72
F1	2328.0	2020.4	2166.72
F#1	2216.0	1929.2	2074.88
G1	2108.8	1842.0	1986.88
G#1	2006.4 (2007.2)	1758.8	1902.72

A1	1909.6	(1910.4)	1679.2	1822.08
Bb1	1817.6		1603.6	1744.64
B	1729.6	(1730.4)	1531.2	1670.72
C	1646.4		1461.6	1600.00
C#	1566.4	(1567.2)	1396.0	1532.16
D	1491.2		1332.8	1467.20
D#	1419.2		1272.8	1404.96
E	1350.4		1215.2	1345.44
F	1284.8	(1285.6)	1160.8	1288.32
F#	1223.2		1108.0	1233.76
G	1164.0		1058.0	1181.44
G#	1108.0		1010.2	1131.36
A	1054.4		964.6	1083.36
Bb	1003.2	(1003.6)	921.0	1037.44
B	954.8	(955.2)	879.4	993.44
c	908.8		839.6	951.36
c#	864.8	(865.2)	801.8	911.04
d	832.2		765.6	872.32
d#	783.2	(783.6)	730.8	835.36
e	745.6		698.0	800.00
f	709.6		666.4	766.08
f#	675.2		636.4	733.60
g	642.4	(642.8)	607.6	702.48
g#	611.6		580.4	672.72
a	582.0		554.0	644.16
bb	554.0		529.0	616.88
b	527.2		505.1	590.72
c1	501.6	(501.8)	482.3	565.68
c#1	477.4	(477.6)	460.5	541.68
d1	454.4		439.7	518.72
d#1	432.4	(432.6)	419.8	496.72
e1	411.6		400.9	475.68
f1	391.6	(391.8)	382.8	455.52
f#1	372.8		365.4	436.16
g1	354.8		349.0	417.68
g#1	337.6		333.2	400.00
a1	321.2	(321.4)	318.2	383.04
bb1	305.8		303.8	366.80
b1	291.0		290.2	351.24
c2	277.0		277.0	336.36
c#2	263.6		264.5	322.08
d2	250.8	(250.9)	252.5	308.44
d#2	238.7	(238.8)	241.1	295.36
e2	227.2		230.3	282.84
f2	216.2	(216.3)	219.85	270.84
f#2	205.8		209.9	259.36
g2	195.8	(195.9)	200.4	248.36
g#2	186.4		191.4	237.84
a2	177.4		182.7	227.76
bb2	168.8		174.5	218.08
b2	160.6	(160.7)	166.6	208.84
c3	152.9		159.1	200.00
c#3	145.5		151.9	191.52

d3	138.5		145.1	183.40
d#3	131.8		138.5	175.62
e3	125.4	(125.45)	132.25	168.18
f3	119.35	(119.4)	126.25	161.04
f#3	113.6		120.55	154.22
g3	108.1	(108.15)	115.15	147.68
g#3	102.9		109.925	141.42
a3	97.9	(97.95)	104.95	135.42
bb3	93.2		100.2	129.68
b3	88.7		95.7	124.18
c4	84.4		91.35	118.92
c#4	80.3	(80.35)	87.25	113.88
d4	76.45		83.3	109.04
d#4	72.75		79.55	104.42
e4	69.25		75.9	100.00
f4	65.9		72.55	95.76
f#4	62.7	(62.725)	69.75	91.70
g4	59.675	(59.7)	67.125	87.81
g#4	56.8		63.125	84.09
a4	54.0	(54.075)	60.275	80.52
bb4	51.425		57.575	77.11
b4	48.95	(48.975)	54.95	73.84
c5	46.6		52.475	70.71
c#5	44.35		50.1	67.71
d5	42.2		47.85	64.84
d#5	40.15	(40.175)	45.675	62.09
e5	38.225		43.625	59.46
f5	-		41.65	56.94
f#5	-		39.775	54.52
g5	-		37.975	52.21
g#5	-		36.275	50.00
a5	-		34.875	47.88
bb5	-		33.5625	45.85
b5	-		31.5625	43.905
c6	-		30.1375	42.045

Thus, Sorge presents his scaling method and reveals the secret. The method also extends to the calculation of mouth-height and width.

> 'If one wants to know the width and height of all mouths, he takes, for example, one-fourth of the circumference of 32-foot C [for the width], and of this fourth part, takes again one-fourth [for the height].
>
> 5401.6
> 4)1350.4 width of the mouth
> 4) 337.6 height of the mouth.'[34]

The scale chart is drawn in a similar manner to those

<u>SORGE'S SCALE CHARTS - half on major 9th</u>

AC = mouth-width of C(1) AB/4
GF = mouth-width of d(15) GB/4

AD = mouth-height of C(1) AC/4
GE = mouth-height of d(15) GF/4

AH= radius of C(1) AB/2π
GJ = radius of d(15) GB/2π

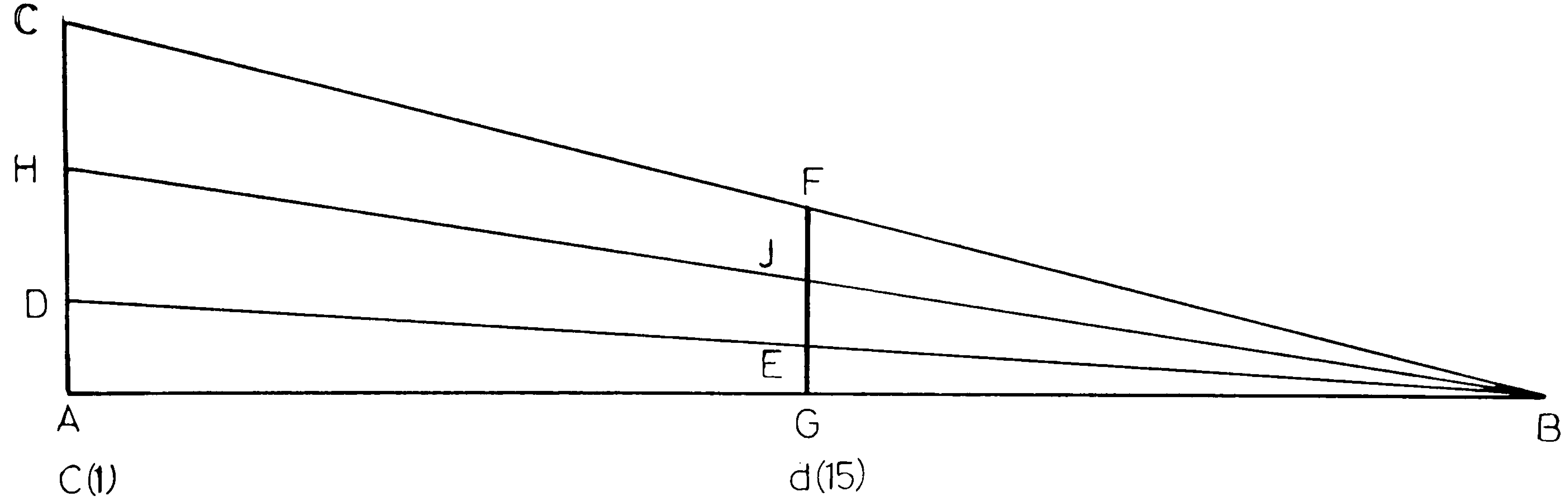


Fig. 7

by Bédos, (see fig. 7). The halving interval is determined, the semitones all calculated as described above and a base-line AB drawn to represent the circumference of the lowest note. The half-measure, when falling on the Major 9th may be represented as GB. One-quarter of the lowest circumference given the mouth-width AC, one-quarter of AC given the mouth-height AD. The measurement for one-quarter of GB, yielding the mouth-width is represented as GF and the mouth-height GE. Sorge calculates the radius of the pipes knowing that 7 *Scrupel* is the radius of a circle of 44 *Scrupel* circumference by means of the 'golden rule' (A:B as C:D)

> '44 given 7; what does 5401.6 give?
> Answer: 859.3'[35]

The radii may thus be given by AH and GJ. Through this process the base-line AB, once divided into the correct number of logarithmic *abscissae*, yields the entire pipe-scale an easily workable chart.

Sorge recommends other mouth ratios recognising that

> 'the tone of a pipe can be altered in many ways by varying the width and height of the mouth.'[36]

and listing 1:3, 1:4, 1:5, 1:6, 2:7, 2:9, 2:11, 3:11, 3:19, 5:19 as examples.

Sorge was an advocate of equal temperament and also of slightly unequal temperaments which enable instruments to accompany the clavier. *The Secretly Kept Art* discusses pipe-length with this in mind. As Sorge points out:

> 'Now if you have two pipes which make up a pure octave, then measure out their lengths and heed how the lengths are proportionate to each other. After this, twelve geometrical mean proportions

> are sought between these two ends. Such can be accomplished either through the extraction of roots according to the usual method, or through logarithmic tables, as I have taught in my *Anweisung zur Rational Rechnung*[37].[38]

The mathematical possibility of determining the pipe-length accurately by calculation had not been established, indeed, we have had to wait for Ingerslev and Frobenius[39] to perfect this calculation from the work of Lord Rayleigh. Sorge was aware of the opportunity to calculate scales based on temperament[40], but for practical use he comments:

> 'Calculation and the art of measuring can't determine exactly the length of the pipes; the ear must do this. Therefore it would be advantageous if one did not cut the length too short, for it is easier to cut off something than to add to it.'[41]

Sorge writes that through experimentation was revealed to him that if 22 *Scrupel* are deducted from a pipe's circumference with respect to its octave, then 7 *Scrupel* must be added in return to its length. Thus, Sorge's proposal of 7:22 ratio (approximately equal to the value of Pi) for the addition to the length of a pipe due to a loss in circumference is put forward:[42]

> 'Since the pipes increase in circumference, as, for example, d3 in one-half as large as c2. Whereas in length it would be half as long as d2, they lose in length approximately one-third of the addition to the circumference'.[43]

Equal temperament was calculated by dividing the Ditonic or Pythagorean comma by twelve, and each fifth calculated to beat flat to an 'acoustically pure fifth' by one twelfth of that comma. The Ditonic comma, or Pythagorean comma being the excess of twelve acoustically pure fifths over a range of seven octaves. Following the circle of fifths around from F to E# *i.e.*, F-C-G-D-A-E-B-F#-C#-G#-D#-A#-E# does not yield the same note, the E# being sharper than the F which started the circle. If we wish to end up with an E# in the same octave as the original F with which it began, it is necessary to drop down by an octave seven times as the circle of 12 fifths is completed. Thus E#:F is

$$(3/2)^{12} \times (1/2)^{7} : 1$$

which is

$$531441:524288$$

or 24 cents difference, almost 1/4 semitone. The Syntonic comma is the excess of four fifths over two octaves and a major third. The Pythagorean major third is sharper than the 'just' major third by the interval 81:80, since

$$(81/64)/(5/4) = 81/80.$$

Similarly the Pythagorean minor third is flatter than the just minor third by the same interval, because

$$(6/5) / (32/27) = 81/80.$$

Sorge divides the Ditonic comma by the Syntonic comma divided into eleven arithmetical parts using numbers from 880 to 891 to represent each increment of 1/12 of the Ditonic comma

0	880
1	881
2	882
3	883
4	884
5	885
6	886
7	887
8	888
9	889
10	890
11	891

Thus, in the example given by Sorge for unequal temperament a

> 'c# of the 8-foot octave would be 7808 [*Scrupel*] in equal temperament, that is, 7 *Fuss*, 8 *Zoll*, and 8 *Scrupel* in length. But in equal temperament it is supposed to be 2/12 of a comma lower. Then the 'rule of three' soon tells me how much longer it must be. For example:

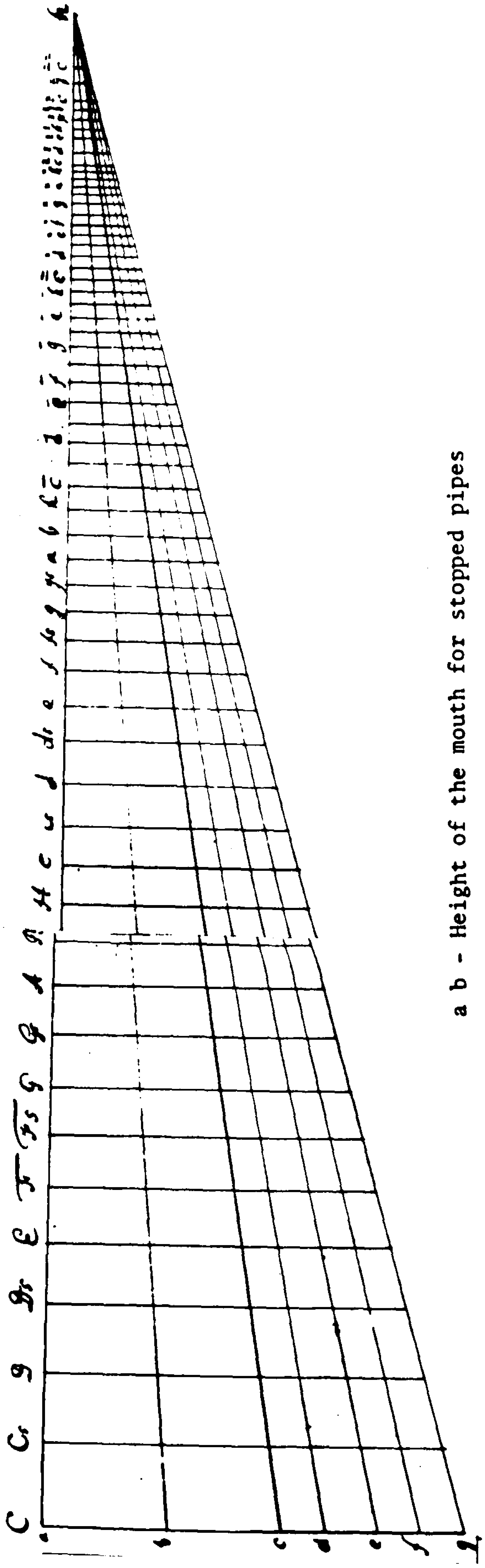
```
             7808
              886
             ----
            46848
           62464
          62464
       ----------
    884)6917888    =    7825 1/2

       Answer : 7825 1/2
```

> Therefore it is 17 1/2 *Scrupel* longer than the c# of equal temperament.'[44]

Carl Bleyle points out that Sorge, in order to avoid the high ration of the 5th near the end of the circle of fifths uses the circle of fourths instead to find the ratio of pitches. This was to be an easy way to compute almost equally tempered intervals.[45] Figure 8 shows an annotated scaling graph in Sorge's own hand.

Marin Mersenne(1588-1648), in his *Sixth Book of the Organ* in *Harmonie Universelle* (Paris, 1635) had experimentally deduced that it was not possible to make a rank of pipes with the same diameter throughout that rank and retain the same tone.[46] Mersenne gives a comprehensive table for the organ manufacturer to calculate the length of pipes, according to various temperaments, and the diameters from widths of 'plates of tin'.[47] This appears to be the source of the scaling chart as it is drawn in Bédos and Sorge, except, of course, the chart in Sorge's work uses

Logarithmic scaling chart in Sorge's hand



a b - Height of the mouth for stopped pipes

a c - Semidiameter [radius]

a f - Width of the mouth for Principal pipes

a e - Width of the mouth for wood pipes

a g - Depth [that is, greater cross-section] of wood pipes

a h - Width of the sheet of metal for Principal pipes

[circumference]

Fig. 8

logarithmic *abscissae*. This type of scaling chart has remained in common use through the last three centuries, although less so since the work of Toepfer[48] has had its effect on organ-building. The scaling slide-rule by Richard Rensch[49] has ousted the use of these charts on the continent of Europe and in North America not for any reason other than that it is comprehensive and reduces the information down to one slide-rule. However, many British builders have yet to understand both the significance of a re-evaluation of scaling practices or even to discover what exactly the scales that are in use in the factory actually represent, progress will be slow in this country.

<u>Johann Gottlob Toepfer</u>

It seems bizzare that in 1905 Audsley should write[50]

> 'There are several old German treatises on scales, but from these absolutely no valuable lessons can be learnt. The art of organ-building, with all its present shortcomings, has advanced far beyond such elementary instruction.'

Presumably Audsley is referring to at least a few works by such writers as Schlick,[51] Virdung,[52] Praetorius,[53] Werkmeister,[54] Bendeler,[55] Samber,[56] Vogt,[57] Neidt,[58] Biermann,[59] Meyer,[60] Sorge,[61] Adlung,[62] Schlimmbach,[63] Wolfram,[64] and Seidel[65]. How curious it is to see how this so-called 'elementary instruction' of Audsley's has begun to dominate the world of organ construction once more. Audsley credits J.G.Toepfer with developing scales whose diameter falls on the sixteenth-, seventeenth- or eighteenth-step. Toepfer credits Sorge with being the first advocate of logarithmic scaling, but the manuscript, *The Secretly kept Art of the Scaling of organ* *pipes*, was presumably unknown to him.

Johann Gottlob Toepfer was born on 4th December 1791 at Viederossla, near to Weimar, in Thuringia[66] and became organist at Weimar Cathedral earning fame as a player, improviser and composer. Toepfer became interested in theoretical problems of the acoustics of the organ partially as a result of reading Sorge's *Der in der Rechen und messkunst erfahrene Orgelbau-meister*. Sumner writes:

> 'At this time, in 1810, Trampeli of the great Silbermann school of organ-builders, had constructed an organ in the town church at Weimar, but strangely, since the Trampeli family was known for the worthiness of its work, the instrument was not a success. It was not satisfactory either mechanically or tonally and was displaced twelve years later.'[67]

In 1824, J.F. Schulze (1793-1858), already aquainted with the work of Wilke[68] and Wolfram, was awarded the contract for remaking the organ according to Toepfer's theories. Toepfer, armed with knowledge culled from Sorge and Bédos, collaborated with J.F. Schulze and produced a 'miraculous transformation'[69] in the instrument's quality. This immediate success brought much credit to the Schulze family, success in which the firm bathed for several decades.

Toepfer set about the task of writing his book *Die Orgelbaukunst* published in Weimar in 1833. It was this publication that was to revolutionise organ-building, not, in retrospect, for the better. Toepfer's book was really only an extension and in part a reproduction of that by Bédos. The remarkably thorough work of Bédos dealt with choice and preparation of material and tools for work at the bench. So did that of Toepfer. Toepfer drew tools such as metal-planers while the firm which moved to Ludwigsburg in 1820, Walcker's, made and sold them.[70] The so-called 'romantic organ' became incredibly popular in central Europe at this time[71] and Toepfer's publication served to give the workman at the bench an ease of construction of components (based mostly on templates) giving full details of pipe-scales, wind chambers, pallets, bellows and action.[72] Despite the republication of Bédos's mammoth treatise in Hamel's *Nouveau Manuel complet du facteur d'orgues* (Paris, 1849), the Toepfer treatise described an organ fashionable in its day, whereas that of Bédos described an essentially obsolete organ.[73]

Toepfer, who admired the work of J.F. Schulze with its early romantic tendency[74] was doubtless influenced by the work of Georg Joseph Vogler (1749-1814) theorist, teacher, organist, pianist and composer. 'Abbé Vogler' had completed his *orchestrion* in 1789[75] in Amsterdam, which went with him on his court tours.

> 'On this instrument he simplified the mechanism, introduced three types of swell to modify the tone, and eliminated low-pitched pipes, compensating for their absence by using combination tones. Essentially, these features form the basis for Vogler's *Simplifikationssystem*, or means of simplifying organ structure that gave rise to strong protest from conservative church organists'[76]

Vogler became almoner (1771) and then court chaplain (1772) in the stimulating environment of the Mannheim court of Carl Theodor the Elector Palatine, whose court was steeped in French culture and the spirit of the enlightenment[77]. Vogler anticipated the work of Helmholz[78] later in the 19th century with his synthesized tones, achieved by mutation stops, touring Europe trying to prove that 16'+10 2/3' + 6 2/5' = 32'.[79] Vogler's theory of organ simplification comprised a limitation of large expensive pipes, the use of free-reeds instead of reed pipes (the American Harmonium is attributable to him), to arrange the pipes semitonally instead of the usual divided or symmetrically disposed chest and to cut down the number of multi-rank mixtures.[80] Thus Vogler sowed the seeds for the destruction of the 'classical organ', for these ideas all manifested themselves in the work of subsequent builders. Vogler's system might be exemplified in in this modification to the organ of St. Peter's, Salzburg (originally Daniel Haill, 1618). Through this method, Vogler saved 525 pipes and left 780.[81]

Original Scheme			(pipes)	Vogler's scheme		(pipes)
Hauptmanual						
Mixtur	2	8Rks	270	Oktav	1	45
Cimbel	1	4Rks	135	Terz	1 3/5	28
Kornett	4	5Rks	127	Terz	3 1/5	37
Superoktav	2		45	Quint	2 2/3	45
Quinte	3		45	Gedackt	4	45
Flöte	4		45	Principal	4	45
Octav	4		45	Gamba	8	45
Gamba	8		45	Nassat	5 1/3	45
Coppel	8		45	(to give 16.ft effect with Principal)		
Principal	8		45	Principal	8	45
Vorderes Manual (Positiv)				Vorderes Manual		
Cimbel	1 1/2	4Rks	135			
Quinte	1 1/3		45	Quinte	1 3/5	26
Superoktav	2		45	Superoktav	2	45
Flöte	4		45	Flöte	4	45
Principal	4		45	Principal	4	45
Coppel	8		45	Coppel	8	45

Pedal

Posaune	8		18
Mixtur	4	4Rks	72
Oktav	4		18
Principal	8		18
Grossbass	16		18
Gamba	16		18
Subbass	16		18

Pedal

Fagott	8	18
Principal	1	18
Principal	2	18
Principal	4	18
Principal	8	18
Principal	16	18
Nassat	10 2/3	18
Gambabass	16	18

In 1801, Vogler published his *Data zur Akustik*[82] from a lecture delivered in Berlin in 1800; this earned him favour with the 'savants'.[83] He endeared himself to the clergy by means of his cost-cutting proposals

> 'convincing many an abbot or conventual head into letting him rebuild the organ according to the latest acoustical notions'.[84]

Mozart apparently saw through him.

> 'He is, to put it bluntly, a trickster pure and simple.'[85]

Williams seems to be convinced that Vogler's simplification system has only had a small role to play in the development of the organ.[86] This is contestable: Vogler's system embodied features, all of which became an intrinsic part of the 19th-century organ either concurrently or consecutively. This was in part due to the influence of Toepfer's work in disseminating the once secretly kept art of organ-building (and in particular scaling) to any organ manufacturer, enabling them to build sturdy, effective-if dull-instruments based on information easily worked at the bench. Vogler's ideas on semitonally planted pipes was followed by many builders of the 19th century (including the Schulze family); Benjamin Joule[87], (sometime organist of St. Peter's, Manchester), described Mr. Jardine as

> 'The first to introduce in this country Professor Toepfer's scales and Abbé Vogler's simplification

system'.[88]

This having been effected before the organs of Edmund Schulze reached the north-west of England in the latter half of the nineteenth-century.

Vogler and his loathesome *orchestrion* was, however, not the only motivating force behind the growing desire for a change in the outlook of the organ. Knecht's *Vollständige Orgelschule* (Leipzig,1795) became an extremely popular treatise in which the author writes

> 'The organ can be regarded somewhat as an imitation of a large orchestra. The advantage a large organ has over an orchestra is that of having a 32' stop and not only 1' and 1/2' stops but compound stops adding a piercing quality to its sonority. For unusual combinations as they occur in 'gallant playing' you can skip from one to three octaves between two stops, and combine on 16' stops with a 2' stop. This will produce a striking effect.'[89]

On the whole, however, mixtures and mutations were becoming less and less popular on account of their association with Vogler's 'acoustical ideas'.

> 'In general, no doubt, mutations and mixtures were less well made in 1820 than they were in 1720, and in any case mixtures are difficult to justify in theory - they seem to contradict certain musical laws. But the better the theorists like Wilke (1839) argued with those who thought that builders made them in order to increase the number of st ps, and pointed out their traditional uses.'[90]

Wilke pointed out in 1839:

> 'Mutations, like mixtures, are highly regarded by many builders partly because prejudice makes them believe they give power to an organ, and partly because the number of stops is thereby increased without much cost or trouble'.[91]

Joseph II of Austria initiated church reforms which considerably reduced the opportunities for the organ builders of the last decades of the 18th century. These led to simplification of the liturgies. By 1820 this had developed into an assumption that the needs of the congregation were sturdy accompaniments for hymns and hence that unison-pitched (8′) stops were the answer to this need.[92]

In England a similar driving force was behind the development of new high-pressure reeds by the 1830's:

> 'Church organ-building as a trade expanded considerably during the early decades of the 19th century (a process which continued into the early years of this century), and the builders were called upon to provide instruments for (amongst other places) the vast new churches thrown up at the expense of the 'Million pound Grant', the Church Building Society, and various other associations for the promotion of church building. The prevailing tastes of the later 18th century had affected the tonal design of the English organ, and it is probably fair to say that the instruments - despite the persistence of the tierce mixture, and the increasingly prominent role played by the unison diapason - lacked both the breadth of tone ("fullness", as contemporaries would have called it) and the generous provision of brilliant upperwork which distinguished the English organ of the earlier 18th century. A light and somewhat insubstantial tone was in favour (rendered partly so by the work of Samuel Green) which, whilst not lacking brightness and an ample provision of refined dulciana and flute tonalities, was inadequate to cope with the vast congregations of the great, rectangular galleried preaching-houses which both Church and Dissent raised in the years following the Napoleonic wars; this inadequacy was apparent enough, and organ builders spent the next fifty years trying to meet the demand for more power in order to suit the acoustics of such buildings. Duplication of ranks was one attempted solution, and...in addition to the very common doubling of the unison rank, one or two builders tried the effect of doubling the reeds.'[93]

Toepfer's treatise of 1833 grew in popularity so much so that an edition in 1855, published as *Lehrbuch der*

Orgelbaukunst in Weimar was in four parts, with 2179 pages and 130 plates[94] and in 1888 the book was brought up to date by Max Allihn as *Die Theorie und Praxis des Orgelbaues*.[95]

The scaling theory of Toepfer was not as profound as its implications. If the cross-section of a pipe was the same throughout the compass, the scaling ratio at the octaves would be $\sqrt{1}:1$, the tone being duller, and flutier and more powerful as the scale ascends. If the pipe proportions were geometrically preserved, the cross-sectional areas at the octaves would be $2^2 :1$ ($\sqrt{16}:1$), yielding a great falling away of power in the treble. A suitable mean is found by taking the geometrical average between

$$\frac{4}{1} \text{ and } \frac{2}{1}, \quad \sqrt{\frac{2x4}{1}} = \sqrt{8} \quad = 2.828433$$

or $\sqrt{8}:1$, where the diameter halves on the major 10th, with its 16 semitones; the diameter at the octaves has a ratio of

$$(2)^{\frac{12}{16}} : 1$$

The area at the octave would then be[96]

$$(2)^{\frac{24}{16}} : 1 = \left(2^{\frac{3}{2}}\right) : 1 = \sqrt{8} : 1$$

If the surface area of a particular note is set at 1, the cross-sections of its lower octaves increase according to the following progression:

$$1:\sqrt{8} \ :\sqrt{8}^2 \ :\sqrt{8}^3 \ :\sqrt{8}^4 \ :\sqrt{8}^5 \ :\sqrt{8}^6 \ :\sqrt{8}^7 \ :\sqrt{8}^8$$

$$1:\sqrt{8} \ : \ 8 \ :8\sqrt{8}:64:64\sqrt{8}:152:152\sqrt{8}:4096\ldots$$

If then the two octaves below behave likewise with regard to diameter and circumference (ie., $1:\sqrt{8}$), then when the dimension of the surface-exterior of a particular note is set at 1, two octaves below $=\sqrt{8}$ and one octave below

$$= \sqrt{1 \times \sqrt{8}} = \sqrt[4]{8},$$

because $\sqrt[4]{8}$ is the average proportional dimension between 1 and $\sqrt{8}$. Thus Toepfer says:

> 'The proportion at which the surface areas, diameters and circumferences of the octave below increase is therefore [97]
>
> $$1 : \sqrt[4]{8}$$

Toepfer shows the calculation of the diameter for 32'C given 2'c = 53mm using the $1:\sqrt{8}$ proportion:

$$\text{The diameter of c0} = 53\sqrt[4]{8} = \log 53 + \frac{\log 8}{4} = 89\text{mm}$$

$$\text{The diameter of C0} = 53\sqrt{8} = \log 53 + \frac{\log 8}{2} = 149\text{ mm}$$

$$\text{The diameter of C1} = 53\sqrt[4]{8^3} = \log 53 + \frac{3\log 8}{4} = 252\text{mm}$$

$$\text{The diameter of C2} = 27 \times 8 = \log 53 + \log 8 = 421\text{mm}$$

Diameters of upper c's in this series are given by

$$\text{The diameter of c2} = \frac{53}{\sqrt[4]{8}} = \log 53 - \frac{\log 8}{4} = 31\text{mm}$$

$$\text{The diameter of c3} = \frac{53}{\sqrt{8}} = \log 53 - \frac{\log 8}{2} = 18.5\text{mm}$$

$$\text{The diameter of c4} = \frac{53}{\sqrt[4]{8^3}} = \log 53 - \frac{3\log 8}{4} = 11\text{mm}$$

$$\text{The diameter of c5} = \frac{53}{8} = \log 53 - \log 8 = 6.5\text{mm}$$

The diameters of the 11 intervening tones between established C's are given by Toepfer in the following manner:

> 'let C be the lower, and c the note one octave higher.

$$c : c\sqrt[12]{\frac{C}{c}} \ :\ c\sqrt[12]{\frac{C}{c}}^{2} \ :\ c\sqrt[12]{\frac{C}{c}}^{3} \ldots\ldots : c\sqrt[12]{\frac{C}{c}}^{12}$$

If the value of $c\sqrt[4]{8}$ is inserted here for C, the size alters to

$\sqrt[12]{\frac{C}{c}}$ [i.e., the major tenth] alters to

$$\sqrt[12]{\frac{c\sqrt[4]{8}}{c}} = \sqrt[12]{\sqrt[4]{8}} = \sqrt[48]{8}$$

and the following progression is obtained for the square of the sides, diameter and circumference of the half-tones:

$$c : c\sqrt[48]{8} : c\sqrt[48]{8}^{2} : c\sqrt[48]{8}^{3} : c \ldots\ldots\ldots : \sqrt[48]{8}^{12} =$$

$$c : c\sqrt[48]{8} \ :c\sqrt[24]{8} \ :c\sqrt[16]{8} \ :c\sqrt[12]{8} \ :c\sqrt[48]{8}^{5} \ :c\sqrt[8]{8} \ :c\sqrt[48]{8}^{7} :$$

c b $b^{\flat}$ a   g#   g   f#   f

$$c\sqrt[6]{8} \ :c\sqrt[16]{8}^{3} \ :c\sqrt[24]{8}^{5} \ :c\sqrt[12]{8} \ :c\sqrt[4]{8} :$$

e   d#   d   c#   C

If, for instance, the diameter of e and g are to be calculated according to this series, when the diameter of

$c = 53mm$, then:

$$e0 = 53 \sqrt[6]{8} = \log 53 + \frac{\log 8}{6} \qquad = 74.7mm$$

and

$$g0 = 53 \sqrt[48]{8} = \log 53 + \frac{5 \log 8}{48} \qquad = 65.5mm$$

Thus Toepfer demonstrates the calculation of intervening semitones. Toepfer points out that although the ratio $1{:}\sqrt{8}$ has much to recommend it[99], it should not be regarded as the only possibility.

> 'It can be maintained that ranks of pipes constructed according to this specification give the greatest regularity in strength and colour of tone. It may be, however, that because of the situation, the conditions, or the wishes of the organ-builder either depth is preferred to height or vice versa; that to depth or height is assigned either greater fullness, or sharpness of tone. This occurs by means of the choice of another ratio such as, for instance, 1:2.5 or 1:2.66'.[100]

Toepfer suggests that changes in cut-up might be employed when the desired ratio is not too far from the ratio $1{:}\sqrt{8}$, but adds

> 'admittedly, however, in as much as the uniformity of tone-colour would be improved the uniformity in strength of tone would be decreased.'[101]

Toepfer warns against the use of extreme scales, and that it is better not to stray too far from his scale of ratio of $1{:}\sqrt{8}$. Toepfer is desirous of negating the experience of builders over the centuries, writing:

> 'Above all, a warning not to trust too much to one's own subjective view of what are considered to be best. The fact must be born in mind that almost every organ-builder has his own formula and each one considers his the best, and that all these formulae are completely different. Routine achieves certain middle values, but it needs correction by means of calculation. Theory does not restrict the freedom of creativity, it does

> not go ahead of the creative spirit, but follows it, controlling and steering the will, and removing peculiarities of taste or habit.'[102]

There are many truths in Toepfer's comments that routine or habit develops sloth. It is only in the last few years that any degree of openness has been exhibited with respect to scaling and particular organ-builder's self-confessed habits. Only recently have British journals begun to publish scales, and this is directly attributable to the pioneering work of Ralph Downes. Many British organ-builders have become alert to the problems and opportunities offered by detailed scaling, but so many are unaware of the precise information contained on the scale rods hanging on the factory wall. Of course, intimate knowledge of this kind is not a virtue in itself and the art of the voicing, the 'imparting of musical speech'[103] is the critical factor, but the overall conception of an instrument's tonality is determined by the process of scaling. The aim of Toepfer's scale was to ensure evenness of tone and the manufacture of such tools as metal planers drawn by Toepfer made for an ease 'obviating capricious and imperfect elements in pipe manufacture'[104] throughout the progression of the stop. The elimination of 'hardness' in voicing a stop was the final stage of this overall smoothness.

Now that voicing and finishing (in some quarters!) has changed its emphasis from starting with the softest Swell Organ stops and working through the organ, to setting all the C's of the organ from the Principal 8', the aim is to 'secure from every pipe its optimum speech for its scale and construction'[105] and thus the pipe sonority changes throughout the compass. Williams comments that Toepfer has perhaps been unjustly maligned for his $1:\sqrt{8}$ scale ratio,[106] and that the (then) contemporary lust for power (so eloquently summarised by Edmonds and Thistlethwaite[107]) and evenness in registration and pipe work must be seen in the light of the developing romantic tendency. It is also true that Toepfer has had too much 'laid at his door' for his simple $1:\sqrt{8}$ formula.[108] No doubt Sumner is correct when he writes that:

> 'Toepfer merely put into a too-rigid mathematical form what had been known to Silbermann, Casparini, and other earlier builders'[109]

but logarithmic scaling was not a crime in itself and the the compilation of such a book is a remarkable feat. Toepfer was not to blame for the general sloppiness in organ construction which was the result of the publication of material so easily transferable to an industrial process. Many scathing criticisms have been made of Toepfer and the resulting 'factory organ'. Although Walcker is a representative example of an 'immensely successful firm'[110] their instruments were, as a result of the introduction of factory production methods, of a consistently good quality. It was the imitators of Schulze in Lancashire and Yorkshire who brought standards low.[111] The exquisite voicing technique of Schulze could not be imitated, although his scales (which were Toepfer's) could, and it was this, coupled with the fact that Schulze[112] was allowed to develop his diapasons in a way which would not have found acceptance in his own country,[113] which partly satisfied and urged on further the lust for power fashionable at that time.

Toepfer, expands his two other scale ratios in an equally confusing way [114] and presents tables of the three scales ratios reproduced below. The pitch nomenclature is Toepfer's.

TABLE FOR THE SCALE-RATIO 1:2.66

Note numb	transp- -osed metal/wood section	circumf.	Width of mouth	Diameter/ depth of wooden pipes	Height of Mouth	Name of note
1	540.9	1909.8	-	608.0	-	C3
2	519.2	1833.5	-	583.6	-	C#3
3	498.4	1760.2	-	560.2	-	D3
4	478.5	1651.0	-	538.0	-	D#3
5	459.4	1622.4	-	516.3	-	E3
6	440.8	1557.6	-	495.8	-	F3
7	423.3	1495.4	-	475.9	-	F#3
8	406.3	1435.5	-	456.8	-	G3
9	390.0	1368.0	-	438.7	-	G#3
10	374.4	1323.2	-	421.2	-	A3
11	359.3	1270.4	-	404.2	-	A#3
12	344.9	1229.5	-	388.2	-	B3
13	331.7	1170.8	292.7	372.7	119.0	C2
14	318.5	1124.0	281.0	357.8	113.6	C#2
15	305.7	1079.0	269.8	343.5	108.5	D2
16	293.5	1036.0	259.0	329.7	103.7	D#2
17	281.7	994.6	248.5	316.6	99.0	E2
18	270.0	954.9	238.7	302.9	94.6	F2
19	259.6	916.7	229.2	291.8	90.0	F#2
20	249.0	879.0	219.8	280.0	86.0	G2
21	239.0	844.9	211.2	268.9	82.0	G#2
22	229.6	811.0	202.8	258.0	78.7	A2
23	220.0	778.8	194.7	247.9	75.0	A#2
24	211.6	747.7	186.9	238.0	71.8	B2
25	203.0	717.8	179.5	228.0	68.6	C1
26	195.0	689.0	172.3	219.0	65.5	C#1
27	187.0	661.6	165.4	210.6	62.6	D1
28	179.7	635.0	158.8	202.6	59.8	D#1
29	172.0	609.8	152.5	192.0	57.0	E1
30	165.6	585.0	146.3	186.0	54.5	F1
31	159.0	562.0	140.5	178.9	52.0	F#1
32	152.6	539.6	134.9	171.7	49.7	G1
33	146.5	518.0	129.5	164.8	47.3	G#1
34	140.6	497.0	124.3	158.0	45.0	A1
35	135.0	477.0	119.3	151.9	43.0	A#1
36	129.6	458.4	114.5	145.9	41.0	B1
37	124.0	440.0	110.0	140.0	39.5	C0
38	119.0	422.0	105.5	134.0	37.8	C#0

39	116.6	405.6	101.4	129.0	36.0	D0
40	110.0	389.0	97.3	123.9	34.4	D#0
41	105.6	373.8	94.5	119.0	32.9	E0
42	101.0	358.9	89.7	114.0	31.5	F0
43	97.0	344.5	86.1	109.6	30.0	F#0
44	93.0	330.8	82.7	105.0	28.5	G0
45	89.7	317.5	79.4	101.0	27.3	G#0
46	86.0	304.9	76.2	97.0	26.1	A0
47	82.6	292.7	73.2	93.0	24.9	A#0
48	79.0	281.0	70.3	88.0	23.8	B0
49	76.0	269.8	67.5	85.8	22.8	c0
50	73.0	259.0	64.8	82.0	21.9	c#0
51	70.0	248.6	62.2	79.0	21.0	d0
52	67.3	238.7	59.7	75.9	19.9	d#0
53	64.7	229.0	57.3	72.8	18.9	e0
54	62.0	220.0	55.0	70.0	18.0	f0
55	59.6	211.0	52.8	67.0	17.0	f#0
56	57.0	202.8	50.7	63.0	16.3	g0
57	54.9	194.7	48.7	61.9	15.6	g#0
58	52.7	186.9	46.7	59.5	14.9	a0
59	50.5	179.0	44.8	57.0	14.2	a#0
60	48.6	172.0	43.0	54.8	13.6	b0
61	46.6	165.0	41.3	52.6	13.0	c1
62	44.7	158.7	39.7	50.5	12.5	c#1
63	42.9	152.0	38.0	48.5	12.0	d1
64	41.0	146.0	36.5	46.5	11.4	d#1
65	39.6	140.5	34.1	44.7	10.9	e1
66	38.0	134.8	33.7	42.9	10.4	f1
67	36.5	129.5	32.4	41.0	9.9	f#1
68	35.0	124.0	31.0	39.5	9.5	g1
69	33.6	119.0	29.8	37.9	9.1	g#1
70	32.0	114.5	28.6	36.0	8.7	a1
71	31.0	110.0	27.5	35.0	8.3	a#1
72	29.7	105.6	26.4	33.6	7.9	b1
73	28.5	101.0	25.3	32.0	7.5	c2
74	27.0	97.0	24.3	30.9	7.2	c#2
75	26.0	93.0	23.3	29.7	6.9	d2
76	25.0	89.7	22.4	28.5	6.6	d#2
77	24.0	86.0	21.5	27.0	6.3	e2
78	23.0	82.7	20.7	26.0	6.0	f2
79	22.0	79.0	19.8	25.0	5.7	f#2
80	21.0	76.0	19.0	24.0	5.5	g2
81	20.6	73.0	18.3	23.0	5.3	g#2
82	19.7	70.0	17.5	22.0	5.0	a2
83	18.9	67.0	16.8	21.0	4.7	a#2
84	18.0	64.7	16.2	20.6	4.5	b2
85	17.0	62.0	15.5	19.7	4.3	c3
86	16.7	59.6	14.9	18.9	4.1	c#3
87	16.0	57.0	14.3	18.0	3.9	d3
88	15.0	55.0	13.8	17.5	3.8	d#3
89	14.8	51.8	13.0	16.8	3.6	e3
90	14.0	50.7	12.7	16.0	3.4	f3
91	13.6	49.0	12.5	15.5	3.2	f#3
92	13.0	46.7	11.7	14.8	3.1	g3
93	12.6	44.8	11.2	14.0	3.0	g#3
94	12.7	43.0	10.8	13.7	2.8	a3
95	11.6	41.0	10.3	13.0	2.7	a#3
96	11.0	39.6	9.9	12.6	2.6	b3

97	10.7	38.0	9.5	12.0	2.5	c4
98	10.0	36.5	9.1	11.6	2.4	c#4
99	9.8	35.0	8.8	11.0	2.3	d4
100	9.0	33.7	8.4	10.7	2.2	d#4
101	9.0	32.0	8.0	10.0	2.1	e4
102	8.7	31.0	7.8	9.8	2.0	f4
103	8.0	29.8	7.5	9.0	1.9	f#4
104	8.0	28.6	7.2	9.0	1.8	g4
105	7.7	27.5	6.9	8.7	1.7	g#4
106	7.0	26.0	6.5	8.0	1.6	a4
107	7.0	25.0	6.3	8.0	1.6	a#4
108	6.8	24.0	6.0	7.7	1.5	b4
109	6.5	23.0	5.8	7.0	1.5	c5
110	6.0	22.0	5.5	7.0	1.4	c#5
111	6.0	21.5	5.4	6.8	1.4	d5
112	5.8	20.6	5.2	6.5	1.3	d#5
113	5.5	19.8	5.0	6.0	1.2	e5
114	5.0	19.0	4.8	6.0	1.2	f5
115	5.0	18.0	4.5	5.8	1.1	f#5
116	4.9	17.5	4.4	5.5	1.0	g5
117	4.7	16.8	4.2	5.0	1.0	g#5
118	4.5	16.0	4.0	5.0	0.9	a5
119	4.0	15.5	3.9	4.9	0.9	a#5
120	4.0	14.9	3.7	4.7	0.8	b5
121	4.0	14.0	3.5	4.5	0.8	c6

TABLE FOR THE SCALE-RATIO $1:\sqrt{8}$

Note numb.	circumf.	width of mouth	Diameter Depth of wooden pipes	transposed metal/wood section	Name of note
1	2225.3	556.3	708.2	625.9	C3
2	2130.9	532.7	678.2	601.1	C#3
3	2040.6	510.1	649.5	575.5	D3
4	1956.0	489.0	622.0	551.2	D#3
5	1871.2	467.8	595.5	527.8	E3
6	1792.0	448.0	570.3	505.4	F3
7	1716.0	429.0	546.1	483.9	F#3
8	1643.2	410.8	522.9	463.5	G3
9	1573.6	393.4	500.0	443.8	G#3
10	1506.7	376.7	477.7	425.1	A3
11	1443.0	360.7	459.2	396.9	A#3
12	1381.7	345.4	439.7	389.8	B3
13	1323.2	330.8	421.2	373.2	C2
14	1267.1	316.8	403.2	357.4	C#2
15	1213.4	303.3	386.2	342.2	D2
16	1162.0	290.5	369.9	327.7	D#2
17	1112.7	278.2	354.1	313.8	E2
18	1065.5	266.4	339.1	300.5	F2
19	1020.3	255.1	324.7	287.8	F#2
20	977.1	244.3	311.0	275.6	G2
21	935.6	233.9	297.8	263.9	G#2
22	896.0	224.0	285.2	252.7	A2
23	858.0	214.5	273.1	242.0	A#2
24	821.6	205.4	261.5	231.7	B2
25	786.8	196.7	250.4	221.9	C1

26	753.3	188.3	239.8	212.5	C#1
27	721.5	180.4	229.6	203.5	D1
28	690.9	172.7	219.9	194.9	D#1
29	661.6	165.4	210.6	186.6	E1
30	633.5	158.4	201.6	178.7	F1
31	606.7	151.7	193.1	171.1	F#1
32	580.9	145.2	184.9	163.8	G1
33	556.3	139.1	177.0	156.9	G#1
34	532.7	133.2	169.5	150.2	A1
35	510.1	127.5	162.3	143.9	A#1
36	488.5	122.1	155.5	137.8	B1
37	467.8	116.9	148.9	131.9	C0
38	447.9	112.0	142.6	126.3	C#0
39	429.0	107.2	136.5	121.0	D0
40	410.5	102.6	130.7	115.8	D#0
41	393.3	98.3	125.2	110.9	E0
42	376.7	94.2	119.9	106.2	F0
43	360.7	90.2	114.8	101.7	F#0
44	345.4	86.3	109.9	97.4	G0
45	330.8	82.7	105.3	93.3	G#0
46	316.7	79.2	100.8	89.3	A0
47	303.3	75.8	96.5	85.5	A#0
48	290.4	72.6	92.2	81.9	B0
49	278.1	69.5	88.5	78.4	c0
50	266.3	66.6	84.7	75.1	c#0
51	255.0	63.7	81.1	71.9	d0
52	244.2	61.0	77.7	68.9	d#0
53	225.9	56.5	74.4	65.9	e0
54	223.9	56.0	71.3	63.1	f0
55	214.5	53.6	68.2	60.5	f#0
56	205.4	51.3	65.3	57.9	g0
57	196.6	49.1	62.6	55.4	g#0
58	188.3	47.1	59.9	53.1	a0
59	180.3	45.1	57.4	50.8	a#0
60	172.7	43.2	54.9	48.7	b0
61	165.4	41.3	52.6	46.6	c1
62	158.3	39.6	50.4	43.6	c#1
63	151.6	37.9	48.2	43.1	d1
64	145.2	36.3	46.2	40.9	d#1
65	139.0	34.7	44.2	39.2	e1
66	133.1	33.3	42.3	37.5	f1
67	127.5	31.9	40.5	35.9	f#1
68	122.1	30.5	38.8	34.4	g1
69	116.9	29.2	37.2	32.9	g#1
70	112.0	28.0	35.6	31.5	a1
71	107.2	26.8	34.1	30.2	a#1
72	102.7	25.7	32.6	28.9	b1
73	98.3	24.6	31.3	27.7	c2
74	94.1	23.5	29.9	26.5	c#2
75	90.1	22.5	28.4	25.4	d2
76	86.2	21.5	27.4	24.3	d#2
77	82.7	20.1	26.3	23.3	e2
78	79.1	19.8	25.2	22.3	f2
79	75.8	18.9	24.1	21.3	f#2
80	72.6	18.1	23.1	20.4	g2
81	69.5	17.4	22.1	19.6	g#2
82	66.5	16.6	21.1	18.7	a2
83	63.7	15.9	20.2	17.9	a#2

84	61.0	15.2	18.9	17.2	b2
85	58.4	14.6	18.6	16.4	c2
86	56.0	14.0	17.8	15.7	c#3
87	53.6	13.4	16.9	15.1	d3
88	51.3	12.8	16.3	14.4	d#3
89	49.1	12.3	15.6	13.8	e3
90	47.0	11.7	14.9	13.2	f3
91	45.0	11.2	14.3	12.7	f#3
92	43.1	10.8	13.7	12.1	g3
93	41.3	10.3	13.1	11.6	g#3
94	39.5	9.9	12.6	11.1	a3
95	37.9	9.5	12.0	10.7	a#3
96	36.3	9.1	11.5	10.2	b3
97	34.7	8.7	11.0	9.8	c3
98	33.2	8.3	10.5	9.3	c#4
99	31.8	7.9	10.1	8.9	d4
100	30.5	7.6	9.7	8.6	d#4
101	29.2	7.3	9.3	8.2	e4
102	28.0	7.0	8.8	7.8	f4
103	26.8	6.7	8.5	7.5	f#4
104	25.6	6.4	8.1	7.2	g4
105	24.5	6.1	7.8	6.9	g#4
106	23.5	5.9	7.4	6.6	a4
107	22.5	5.6	7.1	6.3	a#4
108	21.5	5.4	6.8	6.0	b4
109	20.6	5.1	6.5	5.8	c4
110	19.7	5.0	6.3	5.5	c#5
111	18.9	4.7	6.0	5.3	d5
112	18.1	4.5	5.7	5.1	d#5
113	17.3	4.3	5.5	4.9	e5
114	16.6	4.1	5.2	4.7	f5
115	15.9	4.0	5.0	4.5	f#5
116	15.2	3.8	4.8	4.3	g5
117	14.6	3.6	4.6	4.1	g#5
118	14.0	3.5	4.4	3.9	a5
119	13.4	3.3	4.2	3.7	a#5
120	12.8	3.2	4.0	3.6	b5
121	12.2	3.0	3.9	3.4	c6

TABLE FOR THE SCALE-RATIO 1:2.519

Note numb.	circumf.	diameter	transp. metal/wood section	Widths CUT-UP	Height	Name of note
1	1667.2	530.5	472.6	-	-	C3
2	1604.0	516.7	454.9	-	-	C#3
3	1543.6	491.0	437.7	-	-	D3
4	1485.3	472.6	421.2	-	-	D#3
5	1429.1	454.9	405.2	-	-	E3
6	1375.1	437.7	390.0	-	-	F3
7	1323.2	421.2	375.1	-	-	F#3
8	1273.3	405.2	361.1	-	-	G3
9	1225.1	390.0	347.4	-	-	G#3
10	1178.9	375.1	334.2	-	-	A3
11	1134.3	361.1	321.7	-	-	A#3
12	1091.2	347.4	309.4	-	-	B3
13	1040.2	334.2	297.7	262.5	132.6	C2

14	1010.4	321.7	286.6	252.6	126.4	C#2
15	972.4	309.4	275.6	243.1	120.4	D2
16	935.6	297.7	265.3	233.9	114.8	D#2
17	900.3	286.6	255.2	225.0	109.4	E2
18	866.3	275.7	245.7	216.5	104.2	F2
19	833.6	265.3	236.3	208.3	99.3	F#2
20	802.0	255.2	227.3	200.5	94.7	G2
21	771.8	245.7	218.7	192.9	90.2	G#2
22	742.5	236.3	210.6	185.6	86.0	A2
23	704.4	227.3	202.6	178.6	81.9	A#2
24	687.5	218.7	195.0	171.8	78.1	B2
25	661.6	210.6	187.5	163.9	74.4	C1
26	636.6	202.6	180.5	159.1	70.9	C#1
27	612.4	195.0	173.7	153.2	67.6	D1
28	589.4	187.5	167.1	147.3	64.4	D#1
29	567.2	180.5	160.8	140.5	61.4	E1
30	545.8	173.7	154.8	136.4	58.6	F1
31	525.1	167.1	148.9	131.2	55.7	F#1
32	505.2	160.8	143.3	126.3	53.1	G1
33	486.1	154.8	137.8	121.5	50.6	G#1
34	467.8	148.9	132.6	116.9	48.2	A1
35	450.2	143.3	127.7	111.5	46.0	A#1
36	433.0	137.8	122.8	108.3	43.8	B1
37	416.7	132.6	118.1	104.6	41.7	C0
38	401.1	127.7	112.6	100.2	39.8	C#0
39	385.9	122.8	109.2	96.4	37.9	D0
40	371.2	118.1	105.3	92.8	36.1	D#0
41	357.2	113.6	101.4	89.3	34.4	E0
42	343.7	109.2	97.5	85.9	32.8	F0
43	330.7	105.3	93.7	82.6	31.3	F#0
44	318.3	101.4	92.2	79.5	29.8	G0
45	306.3	97.5	86.7	76.5	28.4	G#0
46	294.6	93.7	83.6	73.6	27.1	A0
47	283.5	92.2	80.3	70.2	25.8	A#0
48	272.8	86.7	77.4	68.2	24.6	B0
49	262.4	83.6	74.4	65.6	23.4	C0
50	252.7	80.3	71.5	63.1	22.3	c#0
51	243.1	77.4	68.8	60.7	20.0	d0
52	234.0	74.4	66.3	58.4	20.2	d#0
53	225.0	71.5	63.7	56.2	19.3	e0
54	216.6	68.8	61.4	54.1	18.4	f0
55	208.4	66.3	59.0	52.1	17.5	f#0
56	200.4	63.7	56.9	50.1	16.7	g0
57	193.0	61.4	54.7	46.9	15.9	g#0
58	185.6	59.0	52.6	46.4	15.2	a0
59	178.6	56.9	50.7	44.6	14.4	a#0
60	171.7	54.7	48.7	42.9	13.8	b0
61	165.3	52.6	46.8	41.3	13.1	c1
62	159.1	50.7	45.0	39.7	12.5	c#1
63	153.2	48.7	43.7	38.2	11.9	d1
64	147.4	46.8	41.7	36.8	11.3	d#1
65	141.7	45.0	40.1	35.4	10.8	e1
66	136.5	43.4	38.6	34.1	10.3	f1
67	132.2	41.7	37.2	32.7	9.8	f#1
68	126.3	40.1	35.8	32.1	9.3	g1
69	121.4	38.6	34.5	30.3	8.9	g#1
70	117.0	37.2	33.1	29.2	8.5	a1
71	111.5	35.8	31.9	28.1	8.1	a#1

72	108.2	34.5	30.6	27.0	7.7	b1
73	103.1	33.1	29.2	26.0	7.3	c2
74	100.2	31.9	28.4	23.5	7.0	c#2
75	96.5	30.6	27.3	23.4	6.7	d2
76	92.8	29.4	26.3	23.2	6.3	d#2
77	89.3	28.4	25.3	22.3	6.0	e2
78	85.9	27.3	24.3	21.4	5.8	f2
79	82.6	26.3	23.4	20.6	5.5	f#2
80	79.5	25.3	22.6	19.8	5.2	g2
81	76.6	24.3	21.6	19.1	5.0	g#2
82	73.7	23.4	20.8	18.4	4.7	a2
83	71.5	22.6	20.0	17.7	4.5	a#2
84	68.2	21.6	19.3	17.0	4.3	b2
85	65.7	20.8	18.7	16.3	4.1	c3
86	63.1	20.0	17.9	15.7	3.9	c#3
87	60.8	19.3	17.1	15.1	3.7	d3
88	58.5	18.7	16.5	14.6	3.5	d#3
89	56.3	17.9	15.9	14.0	3.3	e3
90	54.2	17.1	15.4	13.5	3.2	f3
91	52.0	16.5	14.8	13.0	3.0	f#3
92	50.1	15.9	14.2	12.5	2.9	g3
93	48.1	15.4	13.6	12.0	2.7	g#3
94	46.4	14.8	13.0	11.6	2.6	a3
95	44.6	14.2	12.6	11.1	2.5	a#3
96	42.9	13.6	12.0	10.7	2.3	b3
97	41.3	13.0	11.7	10.3	2.2	c4
98	39.7	12.6	11.3	9.9	2.1	c#4
99	38.2	12.0	10.9	9.5	2.0	d4
100	36.8	11.7	10.5	9.0	1.9	d#4
101	35.4	11.3	9.9	8.8	1.8	e4
102	34.1	10.9	9.7	8.5	1.7	f4
103	32.7	10.5	9.3	8.1	1.6	f#4
104	32.1	10.1	8.9	8.0	1.6	g4
105	30.4	9.7	8.5	7.5	1.5	g#4
106	29.2	9.3	8.1	7.3	1.4	a4
107	28.0	8.9	7.9	7.0	1.3	a#4
108	27.1	8.5	7.6	6.7	1.3	b4
109	26.1	8.1	7.4	6.5	1.2	c5
110	24.9	7.9	7.0			c#5
111	24.1	7.6	6.8			d5
112	23.2	7.4	6.6			d#5
113	22.2	7.0	6.2			e5
114	21.4	6.8	6.0			f5
115	20.6	6.6	5.8			f#5
116	19.8	6.2	5.6			g5
117	19.1	6.0	5.4			g#5
118	18.3	5.8	5.2			a5
119	17.7	5.6	5.0			a#5
120	16.9	5.4	4.8			b5
121	16.3	5.2	4.6			c6

Robertson[115] has laid out Toepfer's formula in a more workable form

$$\log.D = \log.d + \frac{n}{m}\log.2 \qquad 1.10$$

Where D is the Diameter of the larger pipe,
d is the diameter of the smaller pipe,
n is the serial number of D,
and m is the step on which the half-measure is to fall.

This formula gives the relative sizes downwards of any pipes in a given scale. Thus, the pipes in an upward series may be given by

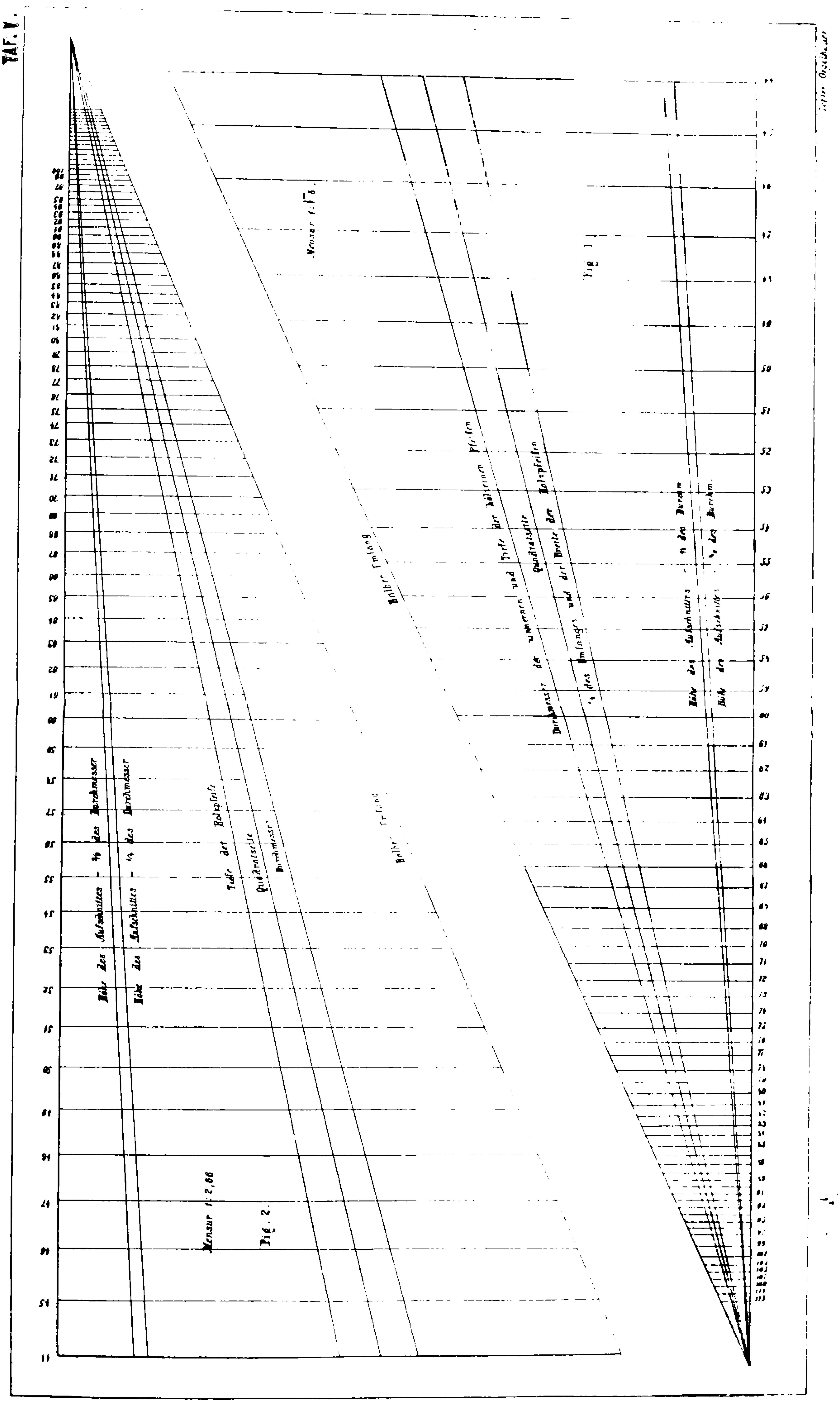
$$log.d = log.D - \frac{n}{m} log.2 \qquad 1.11$$

and the ratio in which the pipes d and D are scaled may be given as

$$m = \frac{n \; log.2}{log.(D/d)} \qquad 1.12$$

There are several methods of drawing a scale: Dom Bédos's method, Sorge's method and its develoment as Toepfer's method. Bédos effecively used a piecewise linear scale, whilst Sorge and Toepfer used logarithmic abscissae on the base-line with perpendiculars joined to each other by the line giving the diameter scale (see figure 9). Conversely, the logarithmic scale may be drawn with equally spaced ordinates on the base line and the diameters given by a logarthimic curve. Some scales are given by Robertson in this form.

The diameters can be represented in two ways: the first method is by the method just described and in the second method, the diameters are plotted as deviations from Toepfer's *Normalmensur*. This latter method will be described in the next chapter.



A logarithmic scale-chart as drawn by Toepfer

Fig. 9

While Robertson (1897)[116] and Audsley (1906)[117] advocated Toepfer's scaling theory and presenting it at some length, Clarke (1877)[118] and Dickson (1881)[119] had devoted a minimum of space to this problem, preferring to discuss it only in relation to the production of wooden pipes. Clarke understood a scale to be 'its diameter or dimensions as compared with its pitch-length'.[120] Clarke gives a diagram for calculating scales (fig. 10) in which *ab* gives the depth or diameter of a pipe, *cb* its width, *db* the mouth-height and *ea* the thickness of the wood for the pipe sides. He recommends that the half-measure of the scale should fall on the sixteenth-step. In Clarke's diagram the base-line is divided into logarithmic abscissae such that the scale-method is identical with Toepfer's.[121]

Dickson's useful little manual outlines a scale-method which, owing to its simple nature is entirely of linear dimensions.[122] The half-measure falls on the seventeenth step or eighteenth note. The base-line between C and f is given as eighteen equally-spaced ordinates (fig. 11). The perpendicular on the first ordinate (C) is given the same measurement for the depth of the wooden pipe, its half-measure falling on f. By halving all the values in the given series, including the distance between the ordinates, the measurements for the next octave are found. This is the closest method in English organ-building literature to that used by Dom Bédos. Dickson's method stands out from the other literature of the time by virtue of its simplicity and use of a purely linear scale for each octave unit.

Clarke's scaling method

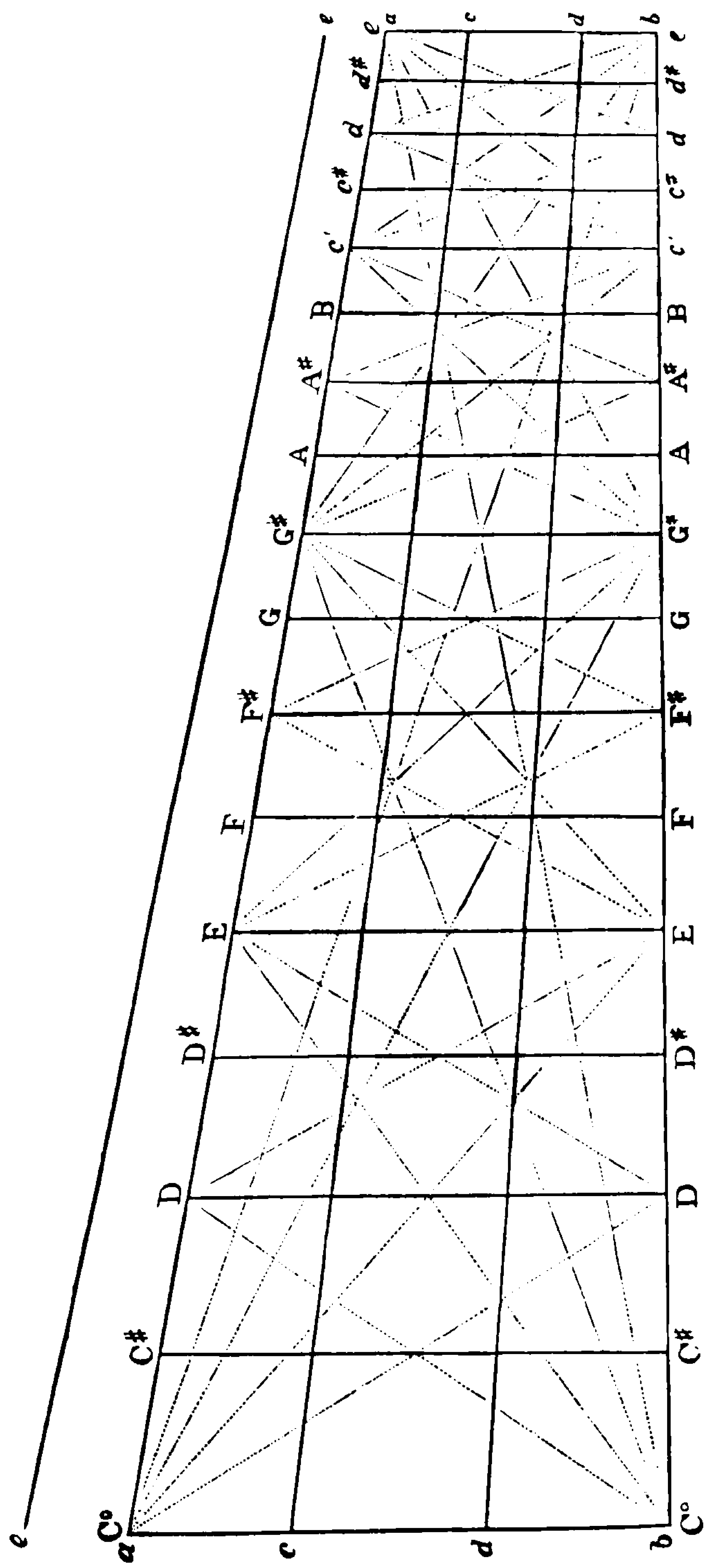


Fig. 10

Dickson's scaling method

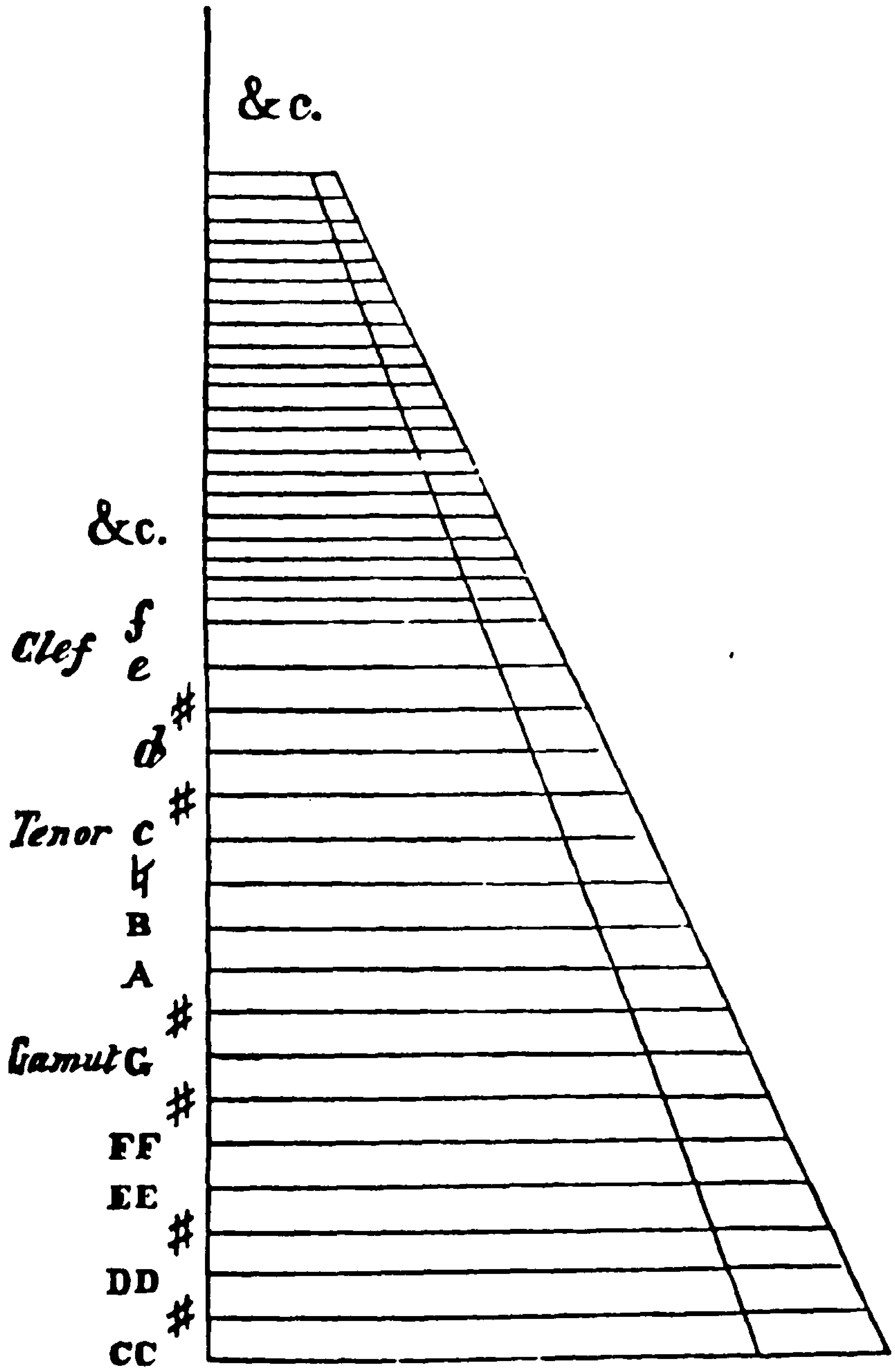


Fig. 11

CHAPTER TWO

CONSTANT OR FIXED-VARIABLE SCALES ?

Scaling and the Orgelbewegung

In 1906, Albert Schweitzer (1875-1965) published a pamphlet entitled *The Art of Organ Building and Organ Playing in Germany and France*[1] in which he attacked the low estate into which he felt that instruments, particularly in Germany, had fallen. The efforts of would-be reformers like Thomas Casson (1842-1910) and, to some extent, Lieutenant Colonel George Dixon (1870-1950) prevented the organ in Britain from careering into a worse situation than that which the introduction of electricity into organ-building actually forced it to. As a reformer Casson knew what he was up against

> 'I premise that if you wish to boast of your organ that it weighs so many tons, has so many score of stops and so many thousand pipes, has so many miles of wire or tubing, requires so many score of horse power to blow it, has so many billions of combinations - arithmetically, not artistically - possible, "like the nails in the horse's shoes, Sammy", I have nothing on which I can inform you'.[2]

The situation was worse in Germany. Schweitzer summarised it thus:

> 'Battle between the commercial and the artistic; victory of the commercial over the artistic'.[3]

Schweitzer insisted that the 'factory organ' was not the answer to the quest for good organ-building, and boldly suggested alternatives. He complained that the texture of a Bach fugue could not be distinguished by the ear through the muddle of sound generated by the modern German organ of his day. There was no comparison between the organs of Gottfried Silbermann and the 'modern organ';

'I had just ended a Bach fugue on a wonderful old Silbermann organ, and was still completely captivated by the magic tone of the old mixtures, when someone next to me, who had his modern organ for two years, remarked, "You know, it must be disagreeable to play on an organ that does not have a single tilting tablet". In his irritation over the old drawstops he had not heard the organ'.[4]

Schweitzer thought more of the French organ of his day, particularly the period between 1850 and 1880 which he regarded as the finest years, when Cavaillé-Coll was at the height of his powers and the representative of the French Romantic organ. Schweitzer considered the French organ to have lost least of its older traits, remaining true to old practices in a way that the German school of organ-builders did not. The scientific methods of Schulze and Toepfer were condemned by Schweitzer, those ideas which became 'routine' and 'habit' with the Romantic organ-builders, and methods which, through Audsley's[5] reverence for Schulze and the theories of Toepfer, infiltrated British and American organ-building practices. Schweitzer was an advocate of the return to tracker action and slider chests, and held that the reasons for the loss of the rückpositiv, in the difficulties of pneumatic action and coupling transmission systems, was not a good enough argument for its loss in musical terms. The lust for power was partly fuelled by the fact that it was cheaper to build a powerful organ of twenty stops than a sweet-toned one of thirty. Schweitzer quotes the following by a distinguished organist of his day:

'We have succeeded now in making an organ of fifteen stops that produces the full effect that formerly an organ of thirty stops produced'[6]

Audsley cites Thomas Pendlebury's claim of his own Geigen Principal 8':

> 'When fully blown, and when given ample speaking room, and played alone in full chords, it delivers as much tone and is quite as brilliant as any full swell of five or six stops known to me, Schulze's work excepted'.[7]

The 'crass commercialism' of the organs of Schweitzer's day which had eclipsed the artistic production of organ *timbre* made him furious.

> 'for in spite of warning voices the complexity of our organs has gradually become a mania with us. If an organ does not look like the central signal room of a great railway station, it is from the very start worthless to a certain category of organists'.[8]

The economic viability of certain economies in organ design allied to the necessity to keep up with the latest inventions in organ manufacture were blamed by Schweitzer as being the crucial issue in the decline of the organ - the question of cost was a final, deciding factor. Yet he was sensitive to the fact that for many organ-builders the decision had to be made to keep up with inventions which reduced prices or else to go out of business. In this way, any concern for the artistic was compelled to bow to commercial considerations.

The 1906 pamphlet provoked a massive response, particularly bitterness from those to whom the work specially addressed itself. Schweitzer was subsequently invited to address the Third Congress of the International Society of Music at Vienna, May 25th to 29th, 1909. Schweitzer diligently prepared for the congress by preparing a questionnaire which was sent to organists and builders in several European countries, a process which, incidentally, also involved Thomas Casson.[9] Part of question four was as follows:

> 'what comments would you make regarding the commonly chosen dimensions and mouths?'[10]

Schweitzer spent many hours sifting through the lengthy replies to his probing questions, and produced a report for the congress. The resulting section to this question in the report pin-points the general concensus that

> 'when we are concerned with wind-pressure and scales we are in the centre of the problem, and that time is past when we may leave the decision in these matters to organ-builders'.[11]

and

> 'General unanimity rules, moreover, in the opinion that the unpleasant total sound effect is indeed partly a result of modern arrangements, but that wind-pressure and scales are in incomparably greater measure responsible for it. Too strong wind-pressure, too narrow scales, too high mouth'.[12]

The introduction of higher wind-pressures for chorus-work had as its natural consequence the introduction of narrow scales and high cut-up to counteract the higher pressures. The higher pressures were the result of a contemporary demand amongst musicians for more power and a taste for 'unnaturally prompt speech in the pipes'.[13] This was due to the elimination of responsiveness in key touch and the desire to have shallower, more 'responsive' pneumatic actions. The economy of building fewer stops for a louder sound with pneumatic action encouraged organ-builders to cut costs further and use the required action-pressure for the speech of the pipes as well. Thus starts the whole circle of problems again: in order to use the same pressure for both moving and sounding parts of the instrument, the pipes had to be forced to speak on pressures hitherto unheard of. The use of high cut-ups and narrow scales yielded the harsh tone in the higher register:

> 'The old measurements, with the exception of the diapasons, are considerably broader, and all have lower mouths. Abnormal wind pressure, abnormal pipes - that is what ails our art of organ-building'.[14]

With diapason scales, the ailment had its roots in the use of larger scales than had been cutsomary in previous centuries. Speech of such pipes was made possible by the higher pressures. Schweitzer reports that

> 'with reference to the scales, many informed persons think that not only the scales themselves are false, but also the interval at which the scales are halved'.[15]

which is the first suggestion that the logarithmic scales and halving ratios recommended by Toepfer were beginning to have some doubt cast upon them. The argument at that time was unclear, the dichotomy being between the use of higher wind-pressures for large acoustics and the use of larger scales in the same situation. It also became apparent that there were many experts in organ-design often in the role of the consultant who were 'wholly uninformed' in this subject and many such experts who thought that such issues were not their concern. Things are only marginally better in this country, even today. Schweitzer's summary in this field is worth repeating:

> 'Concerning the question of scales, the complaint is made in various quarters that

> many organ-builders no longer make their own pipes but get them from factories, and therefore accept the scales and mouths which happen to be in vogue at the time, instead of making their own artistic experiments and copying old and tested scales. In the end, the question of scales is not a problem in higher mathematics and physics, as it sometimes might seem, but a problem of simple artistic experimentation and imitation.'[16]

This section at the congress had little immediate effect, primarily because its interests were in the technical side of organ design rather than the musical side. This could not have been the other way round at that time, when contemporary musical taste was the *dictum* for organ-design. The resulting manifesto, published by Schweitzer[17] became the essence of the *Orgelbewegung*, the successor to the 'Alsatian organ reform'.[18] Although Schweitzer's principles remained as the basis for the reform movement, the development of them was partly outmoded by the 1926 Freiburg Organ Conference, yet these principles were still many years in being introduced effectively . The famous 1921 Praetorius organ based on the description in *De organographia* of 1618, which was the centrepiece of the 1926 conference (built by Oscar Walcker of Ludwigsburg in collaboration with Wilibald Gurlitt) had no proper case work, the stop list was 'improved' on the original conception by Praetorius, the pipes were placed on 'stop channel-chests' not slider chests (which Schweitzer had been advocating in 1906), and the action was electro-pneumatic.[19] The Praetorius organ had to wait for its reconstruction in 1954-5 after the first was destroyed in 1944 to aquire scalings by Praetorius's friend Esaias Compenius, let alone other more basic aspects of the instrument 's original design. In the rejection of 'new' theories of Toepfer and the routine practices of organ-builders, arose the 'lazy uniformity of countless neo-baroque organs built in Germany',[20] which had been initiated in the *credo* that beauty of tone and age were the necessary constituent elements of an instrument's quality.

The Freiburg conference of 1926 gave rise to an even keener interest in the development of the German *Orgelbewegung*. The conference saw papers on all aspects of organ-design, including scaling, with papers given by Oscar Walcker and Hanns Jahnn.[21] Despite Schweitzer's condemnation of the scientific methods of Toepfer, the 1926 Organ Conference unanimously adopted the progression of $1{:}\sqrt{8}$ as the *Normalmensur*, in which the 8'C of the Principal was set at 155.5mm, a measurememt recommended by Dom Bédos[22] for the *Ouvert 8*, although modern thinking has reduced this rather large starting diameter to around 148mm for practical use based on studies of older principal pipework. Using Toepfer's halving ratio of $1{:}\sqrt{8}$, the *Normalmensur* is given as follows:

NORMAL SCALE (*Normalmensur*)

CC	261.519	c	92.416	c2	32.690	c4	11.558	c6	4.086
CC#	250.431	c#	88.541	c#2	31.304	c#4	11.068	c#6	3.913
DD	239.814	d	84.787	d2	29.977	d4	10.599	d6	3.747
DD#	229.646	d#	81.192	d#2	28.706	d#4	10.149	d#6	3.588
EE	219.910	e	77.75	e2	27.489	e4	9.719	e6	3.436
FF	210.587	f	74.454	f2	26.323	f4	9.307	f6	3.291
FF#	201.659	f#	71.297	f#2	25.207	f#4	8.912	f#6	3.151
GG	193.109	g	68.274	g2	24.139	g4	8.535	g6	3.017
GG#	184.992	g#	65.380	g#2	23.115	g#4	8.173	g#6	2.889
AA	177.082	a	62.608	a2	22.135	a4	7.826	a6	2.767
AA#	169.574	a#	59.953	a#2	21.197	a#4	7.494	a#6	2.650
BB	162.385	b	57.410	b2	20.298	b4	7.177	b6	2.537
C	155.500	c1	54.978	c3	19.438	c5	6.872	c7	2.430
C#	148.907	c#1	52.647	c#3	18.613	c#5	6.581		
D	142.594	d1	50.415	d3	17.824	d5	6.302		

D#	136.549	d#1	48.277	d#3	17.069	d#5	6.035
E	130.759	e1	46.230	e3	16.345	e5	5.779
F	125.216	f1	44.270	f3	15.652	f5	5.534
F#	119.907	f#1	42.394	f#3	14.988	f#5	5.299
G	114.823	g1	40.596	g3	14.353	g5	5.075
G#	109.955	g#1	38.875	g#3	13.744	g#5	4.860
A	105.293	a1	37.227	a3	13.162	a5	4.654
A#	100.829	a#1	35.649	a#3	12.604	a#5	4.456
B	96.554	b1	34.137	b3	12.069	b5	4.267

The *Normalmensur*, as represented by the values in the preceding table, may be represented graphically as a straight line, or x axis above and below which (positive and negative) are the number of half tones; each horizontal line is an interval of two half tones, or one whole tone. In this way, deviations from the *Normalmensur*, (depending upon whether the pipe-scale is widening (+) or narrowing (-) with respect to the Toepfer norm) are shown as lines moving away from, or closer to the x axis. Constant scales in the ratio $1:\sqrt{8}$ will appear as lines drawn parallel to the x axis depending upon how many half-tones different the scale is to the Normalmensur. The so-called fixed-variable scales (of, say, Bédos) appear as curves constantly moving closer to or away from the Normalmensur, dependent upon whether the scale is narrowing or widening with respect to the norm on the x axis. Any logarithmic pipe-scale appears as a straight line and the common way of notating these types of scales is by plotting the diameters of the C pipes; the intervening diameters in a logarithmic series will then fall on the line joining the two points at any two C's. The table below shows the more common scaling ratios, and figure 12 plots some of these halving ratios.

Chart of halving ratios (after Mahrenholz)

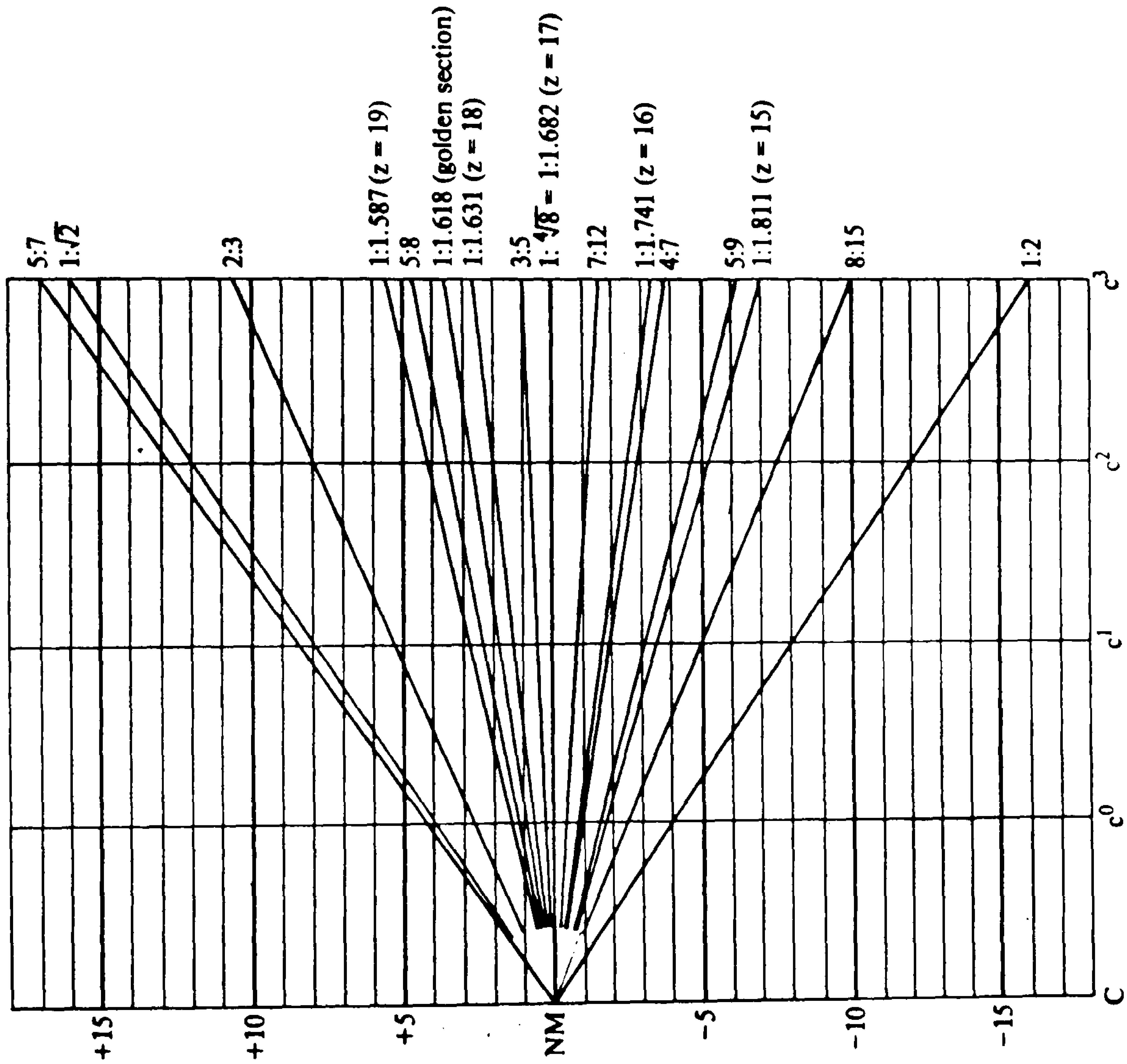


Fig. 12

STEP	RATIO		
11	1:2,1		
11.5	1:2,05		
12	1:2		
12.5	1:1,95		
13	1:1,19		
13,5	1:1,85		
14	1:1,8	(5:9)	
14,5	1:1,75	(4:7)	
15	1:1,73	(1:SQRT 3)	
15,5	1:1,714	(7:12)	
16	1:1,682	(1:4thRT 8)	*Normalmensur*
16,5	1:1,664	(3:5)	
17	1:1,633	(1:SQRT 2,66)	
17,5	1:1,6	(5:8)	
18	1:1,581	(1:SQRT 2,5)	
18,5	1:1,55		
19	1:1,5	(2:3)	
19,5	1:1,45		
20	1:1,4	(5:7)	
20,5	1:1,35		
21	1:1,3	(10:13)	

Arp Schnitger

The *Ubermensch*, the idol of the *Orgelbewegung*, was Arp Schnitger (1648-1719) provoking such misguided statements by Klotz as 'it is the large Schnitger organ that best corresponds to the demands made by J.S. Bach's music.[23] misguided partly because it is still virtually impossible to understand exactly what sound Schnitger was striving for. Schnitger's scalings show many incongruities which Williams rightly ascribes to

> 'Schnitger's careful use of old pipes and his well-planned employment of many apprentices [which] can help to explain same of his organ's inconsistent qualities, such as the differences in scaling between one organ and another of comparable size and scope'.[24]

Williams is inaccurate in describing the Schnitger halving ratios for the tenor register of Prinzipals as being 'fairly constant at $1:\sqrt{8}$.[25] The progression $1:\sqrt{8}$ has become synonymous with Toepfer's theories and hence with a logarithmic pipe-scale. The progressions of the stops do not follow Toepfer's logarithmic scales, although they do halve reasonably consistently on the major 10th in the tenor range. There are other similarities between certain stops in Schnitger's work, although there is no consistency in scaling

> 'partly because of the surroundings ([the organ at] Cappel might have been quite different had it been built for that church),[26] and partly because he followed both his own caprice and that of the previous builder whose instrument he happened to be rebuilding'.[27]

Details of Schnitger scales are difficult to obtain;[28] none of the publications by Dr. Fock[29] are orientated towards technicalities such as scaling. The primary source is Reinburg.[30] The following scale-graphs include scales from other builders - pipework incorporated by Schnitger into his schemes. It is interesting to note that of the few organs used in these graphs, the similarity between certain registers is remarkable. Of course, there is a real danger of confusing similarities in scaling practice of one builder with similarities between stops of a particular variety scaled in a similar manner. There are obvious similarities, for example, in *quintadena* scales; such stops are necessarily very narrow in the bass register and become extremely wide in the treble. Because of this, virtually all organ-builder's *quintadena* scales will look superficially similar. Wide-scaled flute stops such as gedackts fall within certain scaling limits, for if scaled narrower with a low mouth become *quintadena* stops, and if narrower still, the nineteenth-century *Lieblich* variety. Figure 13 shows a similarity in scaling which the is very

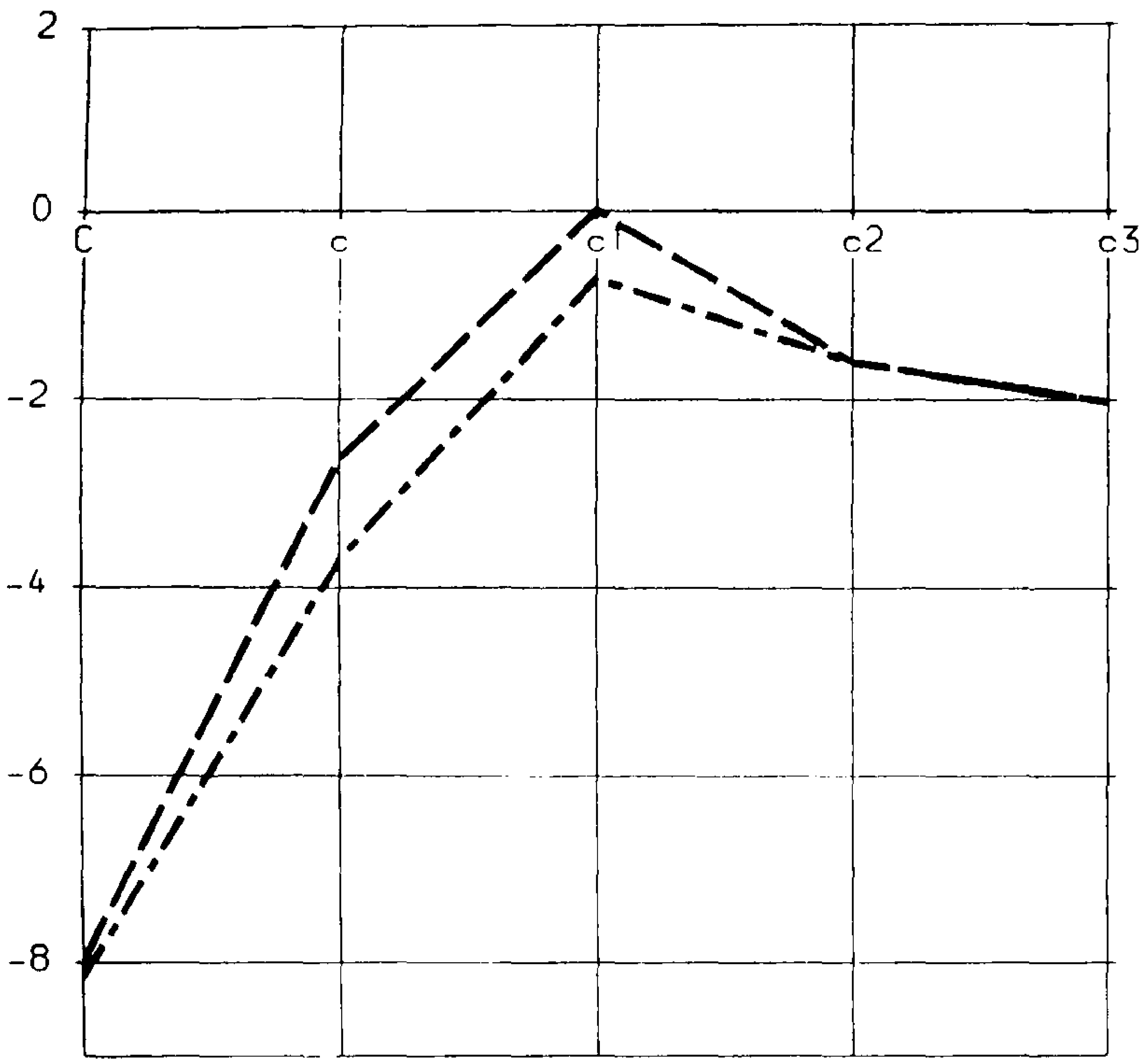


Fig. 13

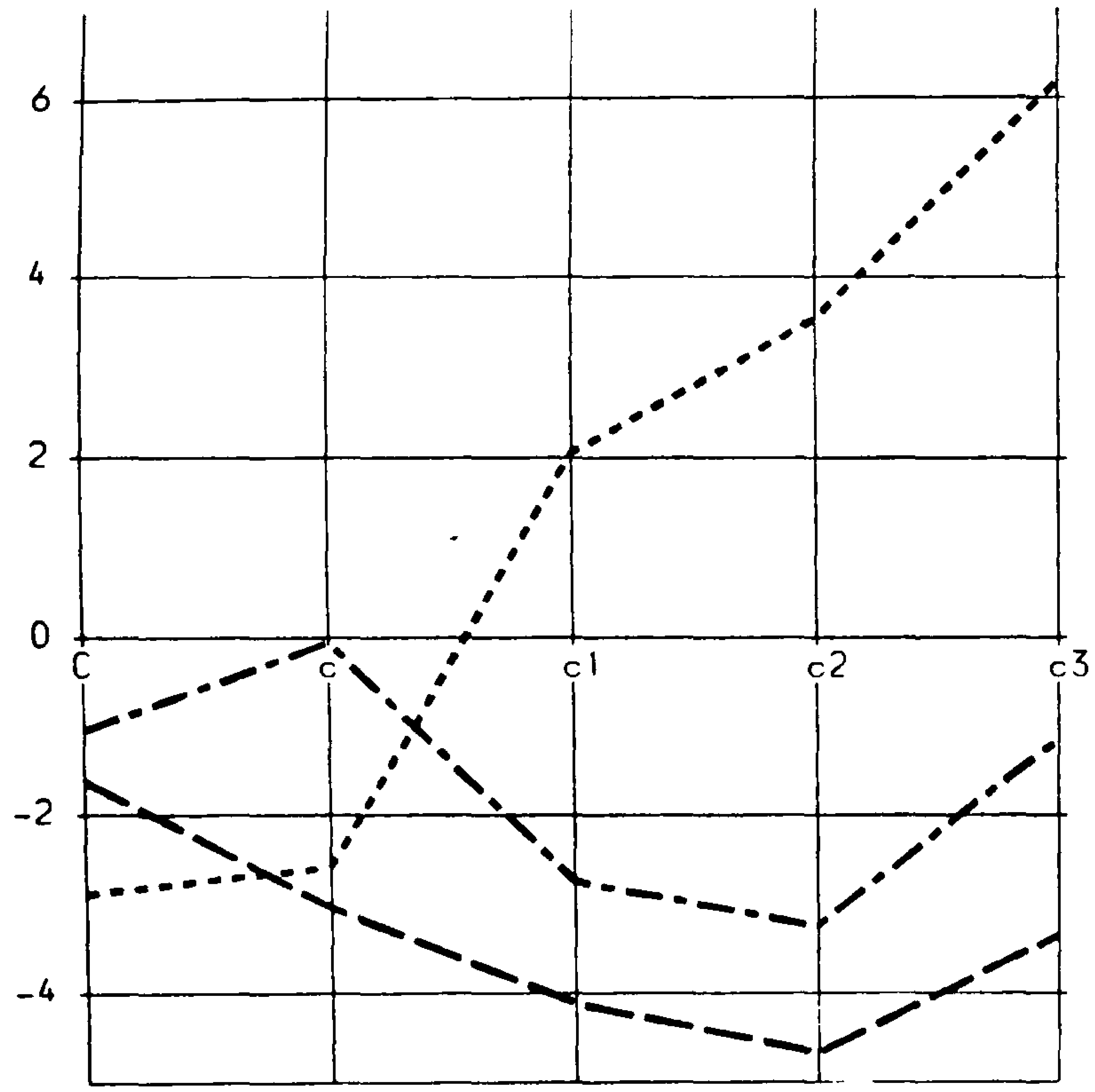
COMPARISON OF ROHRFLÖTE 8′ STOPS

– · – · – · – MITTELKIRCHEN Rohrflöte 8′ (HW) Schnitger rebuild, 1688.

– – – – – – – STEINKIRCHEN Rohrflöte 8′ (HW) 1685-87, mostly prior to Hoyer obviously not accidental. There are traps, however: Downes[31] mistakenly attributes the Steinkirchen *Rohrflöte* to Arp Schnitger, when in fact the flute pipes extant at Steinkirchen are partly by Dirk Hoyer (1540) and part Schnitger who either repaired or added C-E, g#2, and b2-c3. The *Rohrflöte* at Mittelnkirchen (1688) is thought to be entirely by Schnitger. It seems reasonable to assume that Schnitger may have copied the Hoyer scale for Mittelnkirchen whilst working at Steinkirchen the year before. This, although interesting, does not indicate a consistent rationale for all Schnitger's *Rohrflöte* stops. The scalings of the two stops are given below.

Rohrflöte scales	C	c	c1	c2	c3
Steinkirchen[32]	110.0	84.2	55.0	30.5	17.8
Mittelnkirchen[33]	109.2	78.7	53.3	30.5	17.8

There are, however, plainly some similarities in the scales shown in figure 13 although without more evidence these may not allow conclusions to be drawn about Schnitger's scaling practices in general. In most cases for figures 14 to 18 there is a tendency to widen the scales considerably in the last octave. this is a feature of Schnitger scales taken as a whole, and may be as much a comment on the manufacturing practices of small pipes in general, which are more difficult to make, as on the scaling practices of Schnitger. Dom Bédos's scales are seldom given below 5mm, and organ-builders today will rarely make pipes narrower than 4mm diameter. This argument does not hold for the top registers of lower pitched stops, as there is no need to avoid narrow scales when the



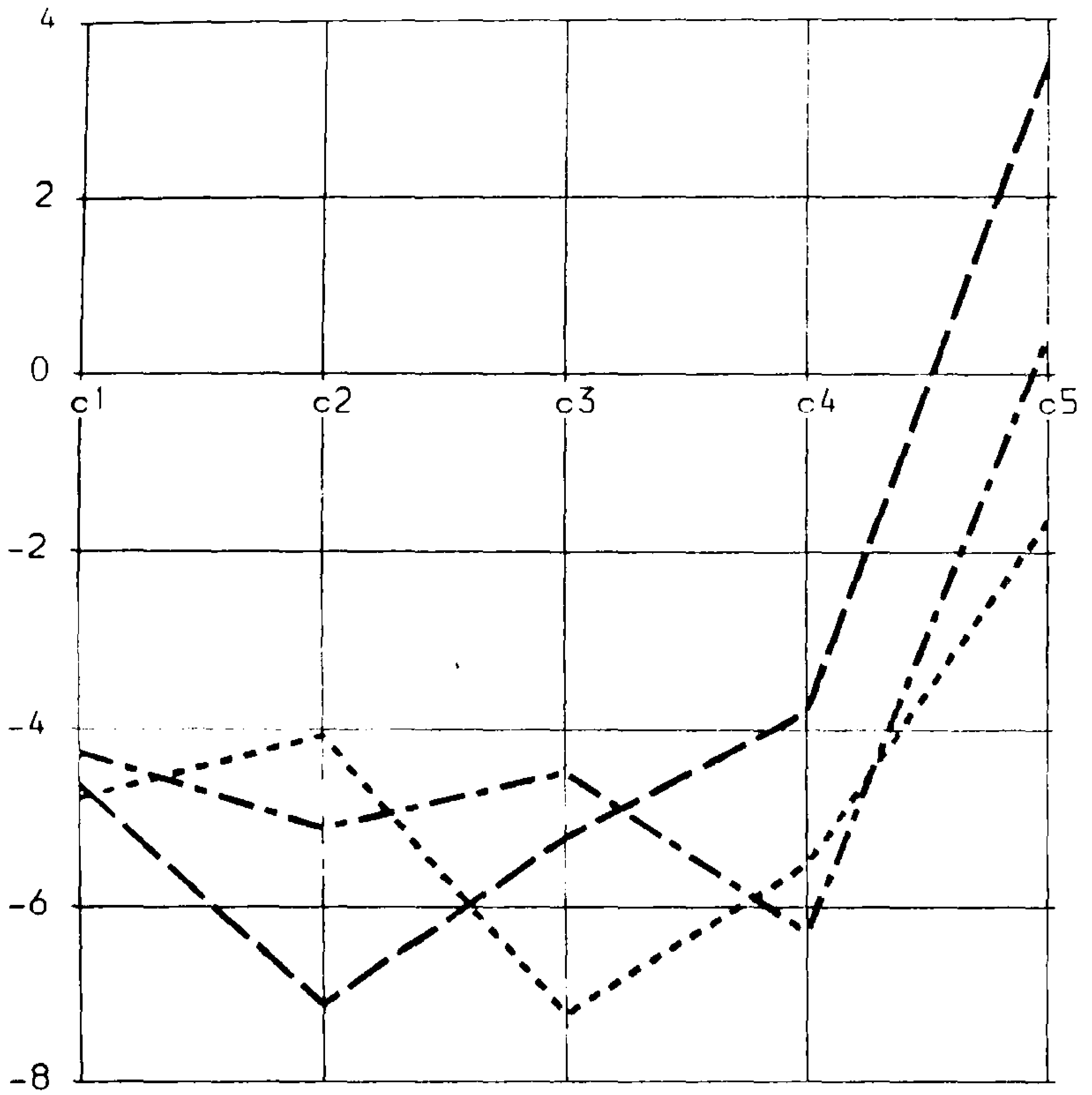
8 ft PRINZIPAL CHARACTERISTICS

Prinzipal 8' (HW) MITTELNKIRCHEN

Prinzipal 8' (HW) STEINKIRCHEN 1685-87

Prinzipal 8' (HW) CAPPEL 1680

Fig. 14



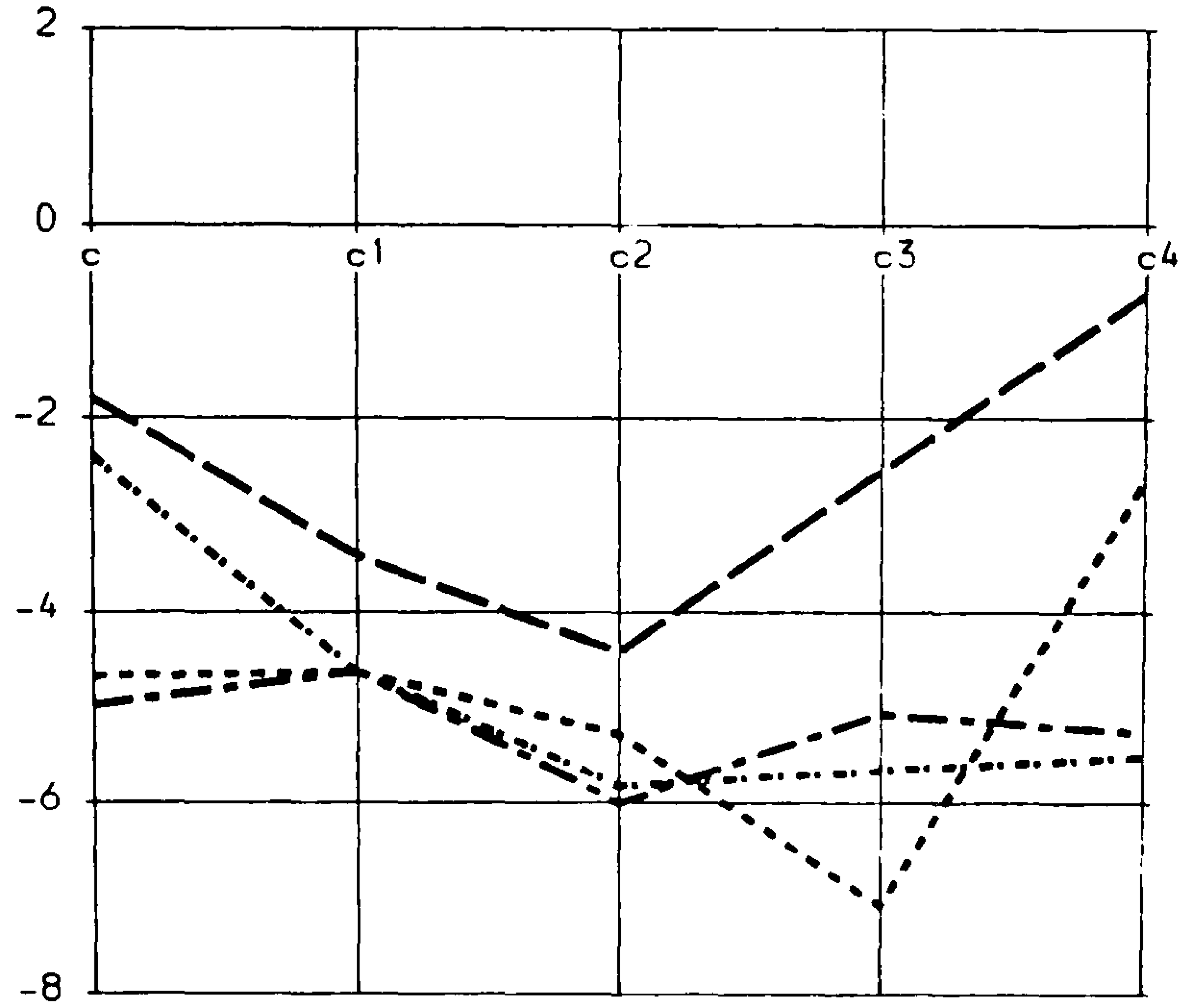
2 FOOT HW OKTAV CHARACTERISTICS

Superoktav (HW) MITTELNKIRCHEN

Oktav 2'(HW) STEINKIRCHEN (Prior to Hoyer)

Octaaf 2' NIEUW SCHEEMDA

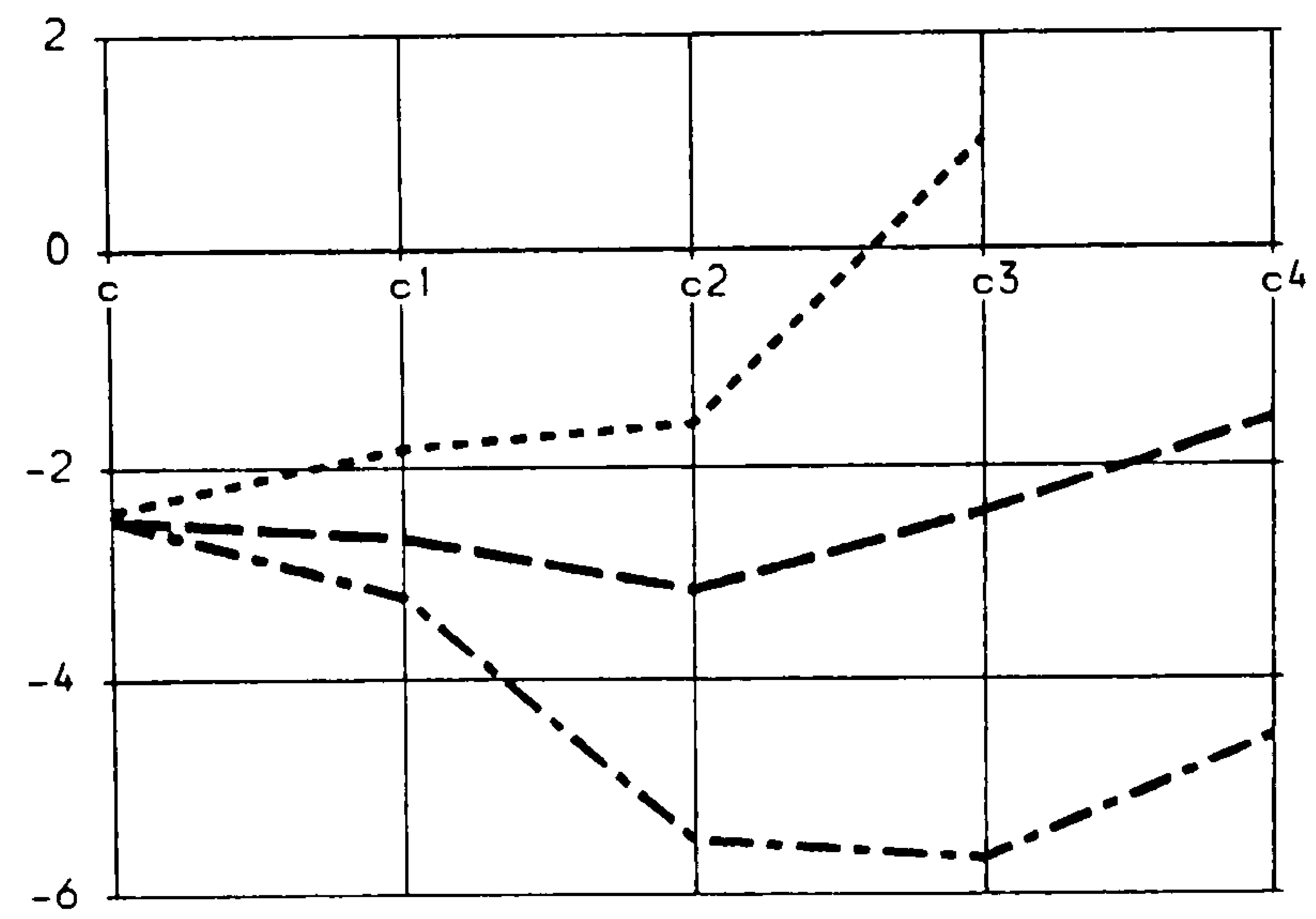
Fig. 15



4 FOOT PRINZIPAL CHARACTERISTICS

Prinzipel 4' (HW) MITTELNKIRCHEN
Octav 4' (HW) CAPPEL
Oktave 4' (HW) STEINKIRCHEN
Praestant 4' NIUEW SCHEEMDA

Fig. 16



4 FOOT PRINZIPAL CHARACTERISTICS

Prinzipal 4´ (BW) MITTELNKIRCHEN

Prinzipal 4´ (RP) CAPPEL

Prinzipal 4´(BW) DEDESDORF

Fig. 17

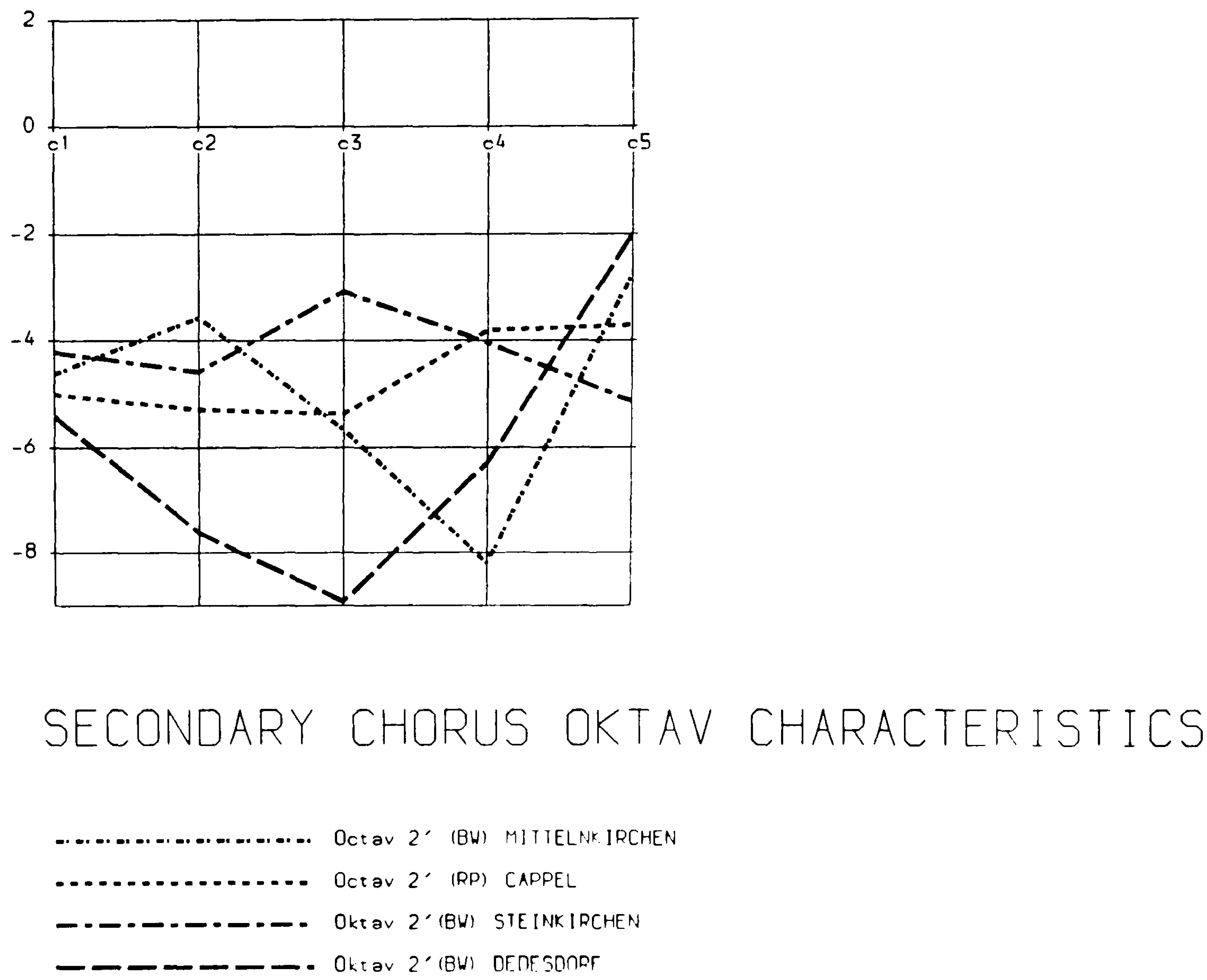

2
0
-2
-4
-6
-8
c1
c2
c3
c4
c5
SECONDARY CHORUS OKTAV CHARACTERISTICS
Octav 2´ (BW) MITTELNKIRCHEN
Octav 2´ (RP) CAPPEL
Oktav 2´(BW) STEINKIRCHEN
Oktav 2´(BW) DEDESDORF

Fig. 18

diameters are still quite large. Figures 16 and 18 show two stops in each with a tendency to halve fairly consistently on the 16th step right up to the top of the register. The table of Schnitger scales below indicates the halving step between each octave. The scales, taken collectively (but not without exception), halve their diameter on the 16th step with a general tendency in these examples to narrow in the middle register, and widen in the last octave. There are exceptions; the 8′ *Prinzipal* from the Mittelnkirchen *Hauptwerk* widens from tenor C, as does the Nieuw Scheemda 2′ *Octaaf*. There are striking similarities between the scalings of the Steinkirchen *Octave* 4′ and the Mittelnkirchen *Prinzipal* 4′ (both *Hauptwerk* stops), while the small organ for Nieuw Scheemda exhibits a similarity between its 4′ *Praestant* and the Dedesdorf *Prinzipal* 4′ (*Brustwerk*), both of which narrow towards middle C and widen in the last two octaves. There are other similarities in the last three octaves of the 8′ *Prinzipals* of Steinkirchen and Cappel and between the Nieuw Scheemda *Octaaf* 2′ and both Dedesdorf and Mittelnkirchen *Brustwerk* 2′ *Oktav* stops. It is surely significant that the secondary chorus 4′ *Prinzipals* of Mittelnkirchen, Dedesdorf and Cappel all start with a similar diameter, (although figure 17 shows three different approaches to these stops) and almost all of the *Prinzipal* 2′ stops of both primary and secondary choruses exhibit similarities. Perhaps the most closely related scales are those of the Mittelnkirchen 4′ *Prinzipal* and the Steinkirchen *Octav* 4′, both being *Hauptwerk* stops. The scale for the Nieuw Scheemda 4′ *Praestant* has a close affinity to the 4′ *Oktav* stop on the *Hauptwerk* at St. Jakobi, Hamburg (Arp Schnitger, 1689-1693). This stop halves approximately as the 13.5th-step between C and c, 15th-step between c and c1, 17.5th-step between c1 and c2 and 20th-step between c2 and c3.[34] This compares with 14th-step (C to c) 14.7th-step (c to c1) 18.9th-step (c1 to c2) and 18.8th-step (c2 to c3) for the *Octaaf* 4′ at Nieuw Scheemda. Both the 8′ *Prinzipal* and 4′ *Oktav* at St. Jakobi, Hamburg follow each other closely in scale construction,[35] both stops narrowing towards middle C. The *Prinzipal* 8′ does narrow considerably in the last octave which is not consistent with features displayed by much of Schnitger's pipework whilst the St. Jakobi, Hamburg examples are unusual in that they are scaled with obvious similarities; this is also the case with the Steinkirchen, and Cappel *Hauptwerk* choruses where there is a narrowing in the middle register towards middle C and a widening of the diameters, at least in so far as they widen from the narrowest point. This is not the case with the Mittelnkirchen *Hauptwerk* chorus, in which the 8′ *Prinzipal* widens radically after tenor C, although the 4′ and 2′ registers narrow towards middle c before widening, (although only a fractional widening in the case of the 4′ stop).

The scales for Schnitger *Prinzipals* are given below. The figures above the C diameters indicate the halving step between the two C's. Pipework by other builders is indicated, where known.

PRINZIPAL 8'	C		c		c1		c2		c3
HW Steinkirchen	148.7	17.6	92.7	13.0	48.8	15.4	28.4	19.4	18.5
HW Cappel (approx)	145.0	14.3	81.0	14.7	46.0	15.6	27.0	17.5	16.8
HW Mittelnkirchen	137.2	16.4	82.6	26.2	60.1	18.2	38.1	20.5	25.4
(*Ped*) Mittelnkirchen *Oktavbass*	134.6	20.7	90.0	15.9	53.3		-		-

HW OKTAV 4'	C		c		c1		c2		c3
Nieuw Scheemda	85.5	14.1	47.4	14.7	27.0	18.9	17.4	18.8	11.2
Steinkirchen	74.5	16.4	45.0	14.3	25.2	17.3	15.6	15.8	9.2
Mittelnkirchen	83.3	13.5	45.0	14.5	25.4	16.2	15.2	16.2	9.1
Cappel (approx)	75.5	16.1	45.0	15.0	25.8	14.1	14.3	25.4	10.3

SECONDARY CHORUS 4'	C		c		c1		c2		c3
Mittelnkirchen *Prinzipal (BW)*	83.3	16.8	50.8	16.3	30.5	20.4	20.3		-
Dedesdorf *Prinzipal (BW)*	83.0	15.7	49.0	15.4	28.5	17.1	17.5	17.2	10.8
Cappel *Prinzipal (RP)* (approx)	83.0	13.6	45.0	15.2	26.0	15.1	15.0	18.2	9.5

HW CYLINDRICAL 2'	C		c		c1		c2		c3
Steinkirchen *Oktav* 2' (mostly prior to Hoyer)	45.7	15.0	26.2	16.9	16.0	14.0	8.8	36.4	7.0
Mittelnkirchen *Superoktav* 2'	44.7	17.0	27.4	12.7	14.2	18.7	9.1	23.6	6.4
Nieuw Scheemda *Octaaf* 2'	45.0	13.2	24.0	19.0	15.5	18.1	9.8	41.0	8.0

SECONDARY CHORUS 2'	C		c		c1		c2		c3
BW Steinkirchen *Oktav* 2' (prior to Hoyer)	45.8	15.5	26.8	18.3	17.0	14.8	9.7	14.7	5.5

BW Mittelnkirchen *Oktav* 2'		17.5		13.6		13.2		29.3	
	45.0		28.0		15.2		8.1		6.1
BW Dedesdorf		15.5		14.4		20.5		24.9	
	43.5		23.5		13.2		8.8		6.3
RP Cappel (approx) *Oktav* 2'		14.2		17.7		19.6		15.8	
	44.0		24.5		15.3		10.0		5.9

PEDAL *PRINZIPALS* 16'	CC		C		c
Steinkirchen *Prinzipal* 16				17.0	
	wood		145.0		89.0
Mittelnkirchen *Prinzipal* 16				22.5	
	wood		139.7		96.5

PRINZIPAL 8' (Ped)	CC		C		c
		20.7		15.9	
Mittelnkirchen *Oktavbass*	134.6		90.0		53.3
		16.1		13.6	
Steinkirchen *Oktav* 8' (1775, (Wilhelmy)	139.0		83.0		45.0

OKTAVE 4' (Ped)	CC		C		c
		15.1		17.0	
Steinkirchen *Oktave* 4'	80.5		46.5		28.5
		14.3		18.1	
Mittelnkirchen *Oktave* 4'	86.4		48.3		30.5

OKTAV 2' (Ped)	CC		C		c
		22.8		14.3	
Mittelnkirchen *Oktav* 2'	36.6		25.4		14.2

	Wind-pressures (in mm of wind)	Pitch
Dedesdorf	70	3/4 tone sharp
Steinkirchen	64	1/2-3/4 tone sharp

Aristide Cavaillé-Coll

Aristide Cavaillé-Coll (1811-1899) concerned himself with theoretical aspects of organ-building throughout his life. In the aftermath of the French Revolution, the Industrial Revolution had its first effects in England in the 18th-century and France was the first country after

England to indulge in the use of the new machine tools and the resultant mass-production. The many exhibitions both in England and France in the latter half of the nineteenth-century encouraged 'a fever of competitive innovation'[36] that was to engulf almost every aspect of instrument design. The more mechanical an instrument was, the more the opportunity presented itself for technical innovation. The organ suffered more than most instruments. Douglass describes Cavaillé-Coll as

> 'a child of the new century, gifted in mathematics and physics, endowed with the power to conceive and present new combinations of facts or to re-interpret known combinations, and highly motivated in devising new methods and in convincing others of their intrinsic worth'.[37]

Cavaillé-Coll reduced many mechanical problems to mathematical treatment.[38] His evident command of engineering had won him over to the members of the Academy of Fine Arts and in particular to the violinist and composer Henry-Montan Berton (1767-1844), a professor at the Conservatoire de Musique from 1795, conductor variously of the Opéra Comique and Théâtre Italien and President of the special commission of the Academy of Fine Arts. Berton was to chair the appointment of an organ-builder for St. Denis Abbey to the north of Paris and Cavaillé-Coll had had a letter of introduction to him on his arrival in Paris in 1833. Cavaillé-Coll won the contract and the instrument took eight years to build, being completed in 1841. It was with this instrument that Cavaillé-Coll made his first important innovations: the introduction of the Barker lever action,[39] and harmonic stops on heavier wind-pressure (of which he claimed to be the inventor),[40] particularly higher registers of reed-stops (harmonic trebles) to provide an 'augmentation of the treble'.[41] During his life, Cavaillé-Coll published much of his research into organ-building,[42] was a friend of Toepfer in Weimar, and concerned himself with 'things touching on the theory of our art',[43] for Cavaillé-Coll considered it important to learn of such things:

> 'The science of music teaches nothing of the laws of mechanics or acoustics, nor the application of the mechanical arts, which must be understood in order to build a good instrument.'[44]

Aristide Cavaillé-Coll met Toepfer in Weimar in 1856 on a trip to Germany, where he had journeyed ostensibly to hear the new 100-stop Walcker organ at the Cathedral in Ulm.[45] He had previously been in correspondence with him in 1852 in which letter, dated 11th December, he wrote

> 'I secured a copy of your first book when it was published [1833], as well as the supplement you published in 1834. As I do not know German, I had a few chapters explained to me: but by reading the figures over, I was able to get an adequate idea of your work.'[46]

Hamel's *Nouveau manuel complet du facteur d'orgues* (Paris, 1849) contained a translation of part of Toepfer's work; Cavaillé-Coll wrote of it

> 'I believe the author has made many errors, and that your theories have sometimes been poorly represented. I have too high an opinion of your theoretical knowledge to ascribe to you some of the absurd notions found in the "complete" Manual of Organ-building.'[47]

Cavaillé-Coll indicates in this letter that he has no space to elucidate upon the 'many errors' in translation, but in an illuminating letter to Mr. Eugene Marca[48] at

Castelnau-Magnoac in the Hautes-Pyrenees on February 7th, 1851, Cavaillé-Coll wrote

> 'Theory without practical experience is at least as blind as habitual routine. In my opinion, the most beautiful aspect of pure sciences is their application, and I believe that theory must be based on extensive practical foundations in order to be sound. The theory of the organ and other musical instruments still leaves much to be desired. The illustrious author of The Organ-Builder, the learned Benedictine Dom Bédos de Celles preferred not to discuss it in his excellent treatise, in which he clearly and honestly describes the craft of organ-building in the eighteenth century, imparting a practical knowledge of all procedures involved in organ construction. Successors to the learned Benedictine, perhaps with less knowledge than his, launched into theory without sufficient understanding of the practical aspects. Mr. Toepfer of Weimar, a talented organist and learned in the physical sciences, established several theories in the book: from them are derived progressions of pipe dimensions and wind requirements. The only flaw in these theories is that they are not supported by adequate experimental studies. Mr. Hamel, a civil-court judge at Beauvais, has published an Organ-Builder's Manual. He had less work to do than the first two authors, as he published Dom Bédos' text in his first two volumes (unfortunately not in its proper order); and in his third volume he gave a very incomplete and inaccurate translation of Mr. Toepfer's work, along with the various improvements in modern organ-building.'[49]

It is clear that Cavaillé-Coll had a deep respect for the writings of the 'learned Dom Bédos' and the work of François-Henri Cliquot (1732-1790). One contract for Nantes Cathedral organ in 1844 refers to the 'justly famous builder, Clicot'[sic][50] and that particular ranks by Cliquot are 'very well made, excellent tone'.[51] It also seems evident that Cavaillé-Coll used scales from Dom Bédos's work

> 'We should point out that our Plein-jeu consists of the three highest ranks of the Cymbale given in Dom Bédos' book'.[52]

and again, of the *Voix humaine*:

> 'In France as in Germany, this stop is always the worst in the organ...As for the scale itself, you will find but few changes compared to the traditional shape given by Dom Bédos'.[53]

It would seem that Toepfer acted as consultant at the church of *La Trinité*, Marseilles where a certain Mr. Schonnagel was organist; in a letter dated September 10th, 1853, Cavaillé-Coll wrote to Mr. Schonnagel as follows:

> 'I have received in due course your letter and Mr. Toepfer's report...My most sincere thanks for the trouble you took in copying this extensive report. I had one of my employees translate it, and Mr. Toepfer's remarks are quite in agreement with my opinion of the value of the organ and the competence of the builder'.[54]

Being technically minded, Cavaillé-Coll could hardly help being affected by the theoretical work of Toepfer. Cavaillé-Coll set the relationship between metal-thickness and diameter of the pipe as 1:100;

> 'A 16' pipe 30cm. in diameter is 3mm. thick. An 8' pipe 15.7cm. in diameter is 1.57mm. thick. A 4' pipe 11.5cm. in diameter is 1.15mm. thick, and so forth. Since the diameters of pipes between 32' C and 16' C, and between the latter and 8' C, decrease by geometric progression, their thickness also decreases in geometric progression'.[55]

Exactly how practicable Cavaillé-Coll found such a pipe-thickness to diameter relationship is not clear and would require much detailed examination of pipework, and considering this was written in 1836, probably before Cavaillé-Coll had made many (if any) pipes for St. Denis, it is improbable that such accuracy could be adhered to as any scale progression would require casting of metal to an almost infinite gradation of thicknesses. What is more important here is that the Frenchman speaks of a 'geometric progression' - a progression in which the ratio of any term to a subsequent term is constant.[56] Since this was written three years after the publication of Toepfer's work it would seem that he is referring to Toepfer's scale theory.

Cavaillé-Coll was commissioned to build or add to several organs in Great Britain including the Carmelite Church, Kensington (1866), Bracewell Castle, Skipton (1870), The Albert Hall, Sheffield (1873), Bellahouston Church, Glasgow (1874), Paisley Abbey (1874), Blackburn Parish Church (1875), Ketton Hall, Rutland (1875), and Manchester Town Hall (1877). These instruments, being predominantly built in the North-West, as were the instruments of Edmund Schulze, had a major effect on the style of the North-Western organ-builders. The harmonic flutes, harmonic reed trebles and string stops of Cavaillé-Coll were mimicked along with the *lieblich* flutes, manual and pedal quints, and the bold chorus-structures of Schulze. Oddly enough, one of the most characteristic sounds of the Cavaillé-Coll organs, the blazing reed choruses and unweighted tongues were not copied although *vox humana* stops found almost instant popularity. There are many fascinating organs in the North-West of England,[57] representing a happy fusion of two elements of organ construction which along with the more purely English school of Hill fashioned the sound of the British organ well into the twentieth-century.

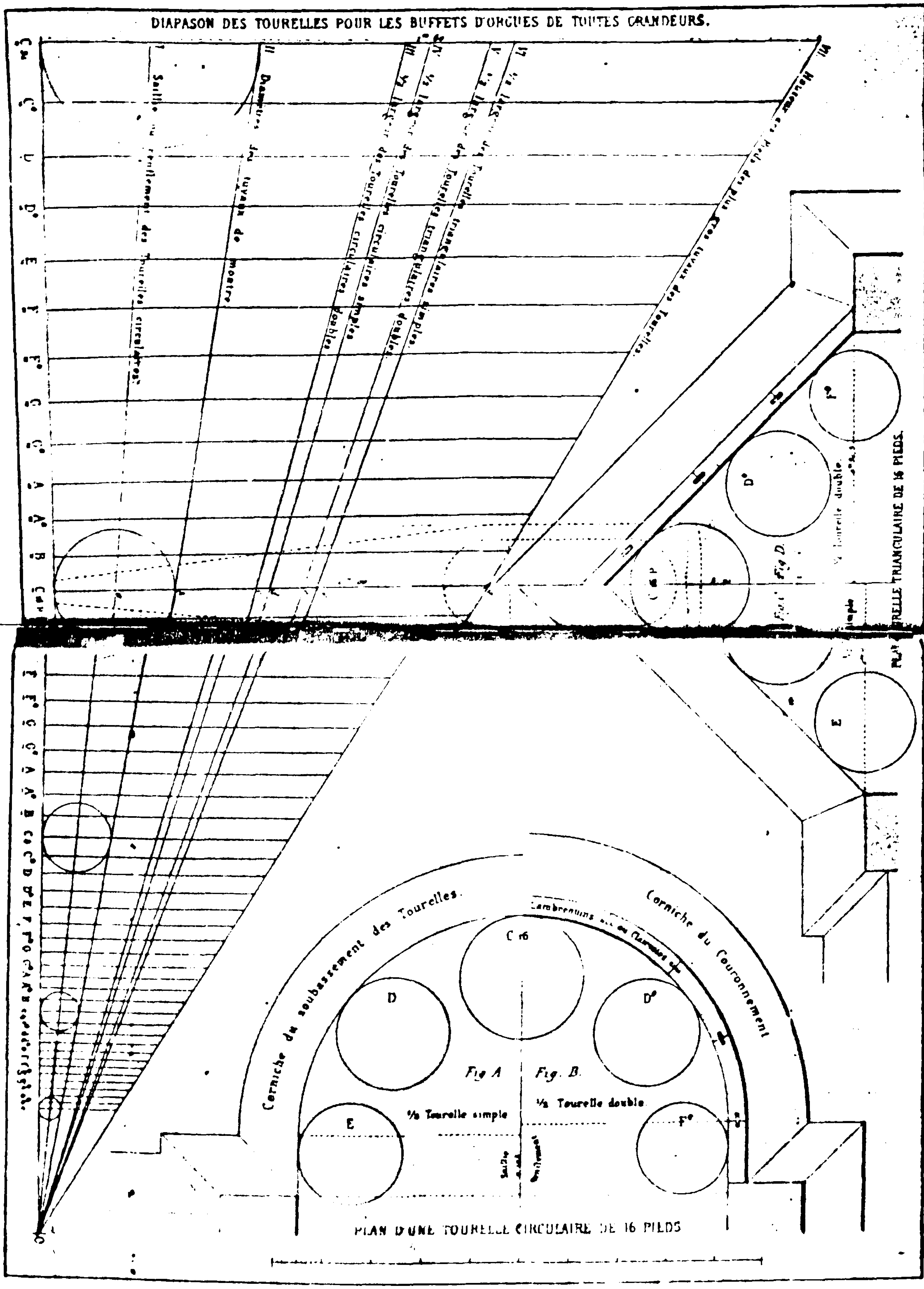
In an unpublished manuscript,[58] the following diameter scales of Cavaillé-Coll are given for open, cylindrical flue-pipes. Using equation 1.12, the calculated half-measure is indicated in the right-hand column.

	C	f	f1	f2	Half-measure on step
Montre	130	-	-	28	18.5
Prestant	80	-	25	-	17.3
Doublette	45	24	-	-	18.7

These scales indicate the use of a geometric progression for the pipe-scale, althougth conclusive proof of his use of Toepfer scales appears in his own paper *De l'orgue et de son architecture* (Paris, 1872).[59] This work contains tables for the dimensions of case-turrets of both circular and triangular shape, the progression of diameters of *montre* pipes and the progression of pipe-lengths for the same. The table below shows Cavaillé-coll's diameter progression halving almost in the ratio 4:7. The semitone halving step is indicated above and between the c measurements. These figures indicate the stop halves consistently on the fourteenth-step. Cavaillé-Coll also published a scaling-chart for these case pipes in the same paper which can be seen at figure 19. The pitch-nomenclature is Cavaillé-Coll's.

DIAMETER PROGRESSION FOR *MONTRE* PIPES

	I 32 foot octave	II 16 foot octave	III 8 foot octave	IV 4 foot octave	V 2 foot octave	VI 1 foot octave
half on	14.4	14.6	14.3	14.5	14.4	
C	450.0	253.8	143.2	80.0	45.0	25.3
C#	428.9	241.2	135.6	76.2	42.8	24.1
D	408.8	229.9	129.3	72.7	40.8	22.9
D#	389.7	219.1	123.2	69.3	38.9	21.9
E	371.4	208.8	117.4	66.0	37.1	20.8
F	354.1	199.1	112.0	62.9	35.4	19.9
F#	337.4	189.7	106.7	60.0	33.7	18.9
G	321.6	180.9	101.7	57.2	32.1	18.0



DIAPASON DES TOURELLES DES BUFFETS D'ORGUES.

par Aristide CAVAILLÉ COLL, facteur d'Orgues. Fig. 19

G#	306.6	172.4	96.9	54.5	30.6	17.2
A	292.2	164.3	92.4	51.9	29.2	16.4
A#	278.5	156.6	88.0	49.5	27.8	15.6
B	265.5	149.3	83.9	47.2	26.5	14.9

Eschbach has written in great detail of the voicing techniques employed in the organ at St.Sulpice, Paris in 1862.[60] It seems evident from this that many stops halve their diameters consistently, following geometric progressions. Although this organ is not necessarily indicative of Cavaillé-Coll's voicing techniques, owing to some problems with the strange shape of the curved organ case designed by Chalgrin, the scalings are indicative of his usual practice. The *Grand-Choeur Doublette* is annotated as having 'no precise half diameter. Nearest step is 12, then step 20, then step 23.'[61] This may represent a Dom Bédos scale (Cavaillé-Coll certainly used, or at least adapted them) but as Eschbach gives no measurements for this stop this question remains unanswered. An interesting comparison may be made between the scale of the *Doublette* 2' on the *Grand-Choeur* and that on the *Positif*. The latter halves consistently on step seventeen, which would indicate that Cavaillé-Coll had a different approach to the scaling of the same stop, an approach which was not dependent upon simple changes of starting diameter.

The Schulze Firm

The firm of Schulze (Johann Andreas Schulze [c.1740-1810], Johann Friedrich Schulze [1793-1853]) passed on to Heinrich Edmund Schulze (1824-1878)[62] had rebuilt Toepfer's organ in Weimar and the design outlook of the firm changed as a result of the collaboration of Johann Friedrich and Toepfer in 1824-25. Evidently Schulze was sufficiently impressed by Toepfer's theories that he was willing to put them into practice. The influence of Toepfer in England came not so much from his writings as through the Schulze firm which Heinrich Edmund took over in 1858. So widespread had Toepfer's ideas become known that Ahllin, in the preface to the 1888 edition of Toepfer's work, records that

> 'Thanks are due to Giesecke and Son of Gottingen, Rover Hausneindorf, Sauer in Frankfurt ... Wal[c]ker of Ludwigsburg, Schiedmeyer of Stuttgart, Gebruder Rieger of Jagerndorf, Sander of Braunschweig, Boden of Halberstadt, Stahlhut of Burtscheid, Welte and Son of Freiburg, Cavaillé-Coll of Paris, Hastings and Hook of Boston, Rosevelt of New York, as may be seen, an impressive list of the greatest names in organ-building. If therefore others, such as the English, have refused their contribution, we can easily get over this.'[63]

The name of the Schulze firm does not appear here as it had closed in 1880.

The up-and-coming builders of the latter half of the nineteenth century in England were heavily affected by the tide of change immediately after the Great Exhibition in Hyde Park, London, 1851. Fourteen organ-builders exhibited instruments, eleven of which were British, other contributions being from German, French and Italian builders. Cavaillé-Coll did not exhibit; Hill produced a 'rather perfunctory instrument'[64] and Henry Willis risked much in exhibiting a three-manual, 70 speaking-stop organ with pistons, which were a new concept at the time.

Edmund Schulze, inherited the full-blooded chorus-structures associated with the German organ, and this was a new phenomenen in England. It was Schulze's organ that attracted most attention at the Great Exhibition.[65]

> 'It had a far-reaching influence in two ways: firstly, organists and enthusiasts were attracted to Germany to see more of Schulze's work and gave him orders for new organs and secondly, the organ-builders copied, as far as they could, his flue stops, and incorporated these in their own instruments.'[66]

Even the Gentleman E.J. Hopkins was

> 'so carried away by his emotions, when he first heard a Schulze organ in a German church, that he had to sit in the churchyard for sometime to regain his composure'.[67]

Edmund Schulze was convinced he had no secrets in his art. The fact was, as Noel A. Bonavia-Hunt has demonstrated (in his quest for the ideal organ tone and the reproduction or copying of Schulze's diapason-choruses) that Schulze was a superb voicer and this, allied to certain modes of construction in his flue pipes, gave his instruments a sound unique to English ears. Schulze set his pipework on huge sound-boards, and Bonavia-Hunt recognised that

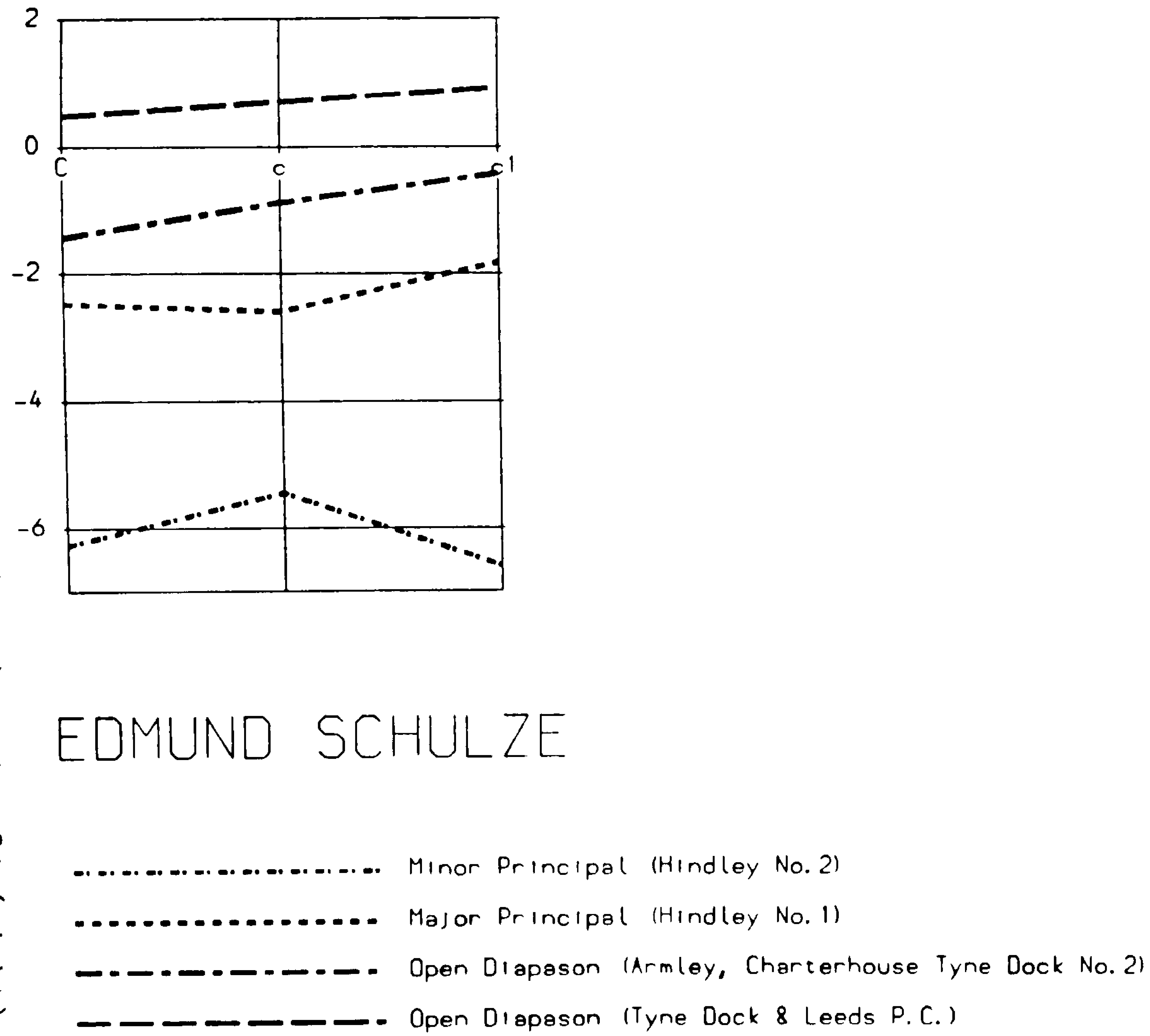
> 'A generous supply of wind from the sound-board was a cardinal principle with Schulze; indeed a dismal failure awaits the student who neglects this essential condition, no matter how perfectly the pipes may have been prepared ....It must be remembered that *volume* or cubical capacity is of far importance than *pressure* of wind'.[68]

Schulze's scales follow exactly the halving-ratios of Toepfer with the exception of the Doncaster Great Open Diapason I (now designated number II, the present large Great Open Diapason being added by Hill, Norman & Beard in 1905).

Edmund Schulze apparently followed Toepfer's book, if not almost to the letter, then certainly as far as 'the methods of choosing and seasoning the wood'.[69] Schulze built organs mainly in the North of England. Instruments were installed at Doncaster Parish Church (1862), The Exchange Room, Northampton (1851 Exhibition organ) St. Peter's Hindley, Lancashire (1873), Meanwood Towers in Leeds (1869) [now in St. Bartholomew's church, Armley], St. Mary's, Tyne Dock (1864 and 1874), [now at Ellesmere College], and installed pipework in many other organs, the most important being at Charterhouse, St. Peter's Church Harrogate (1879), Leeds Parish Church, St. Marylebone Church, London, and at Seaton Carew. Schulze used some enormous scales, those of some of his 8' diapason-stops are listed below. Figures 20 to 22 show these scales plotted against the *Normalmensur*. Any line parallel (or virtually parallel) to the central axis indicates the use of ratios halving on the sixteenth-step or seventeenth-pipe.

Edmund Schulze 8 ' Principal stops

Instrument at	C		c		c1		c2
Doncaster Parish church (Gt.)	165.1	13.7	90.0	11.8	44.5	24.8	31.8
Tyne Dock & Leeds Parish Church. (Gt.)	158.8	16.3	95.3	16.3	57.2		-
Armley, Charterhouse, and Tyne Dock No. 2. (all Gt.)	146.1	16.8	89.0	16.7	54.0		-
Hindley No. 1	139.7	15.8	82.6	17.1	50.8		-
Doncaster Swell Open Diapason	wood	-	82.6	17.1	50.8		-
Hindley Swell Open Diapason	133.4	16.0	79.4	16.3	47.7		-



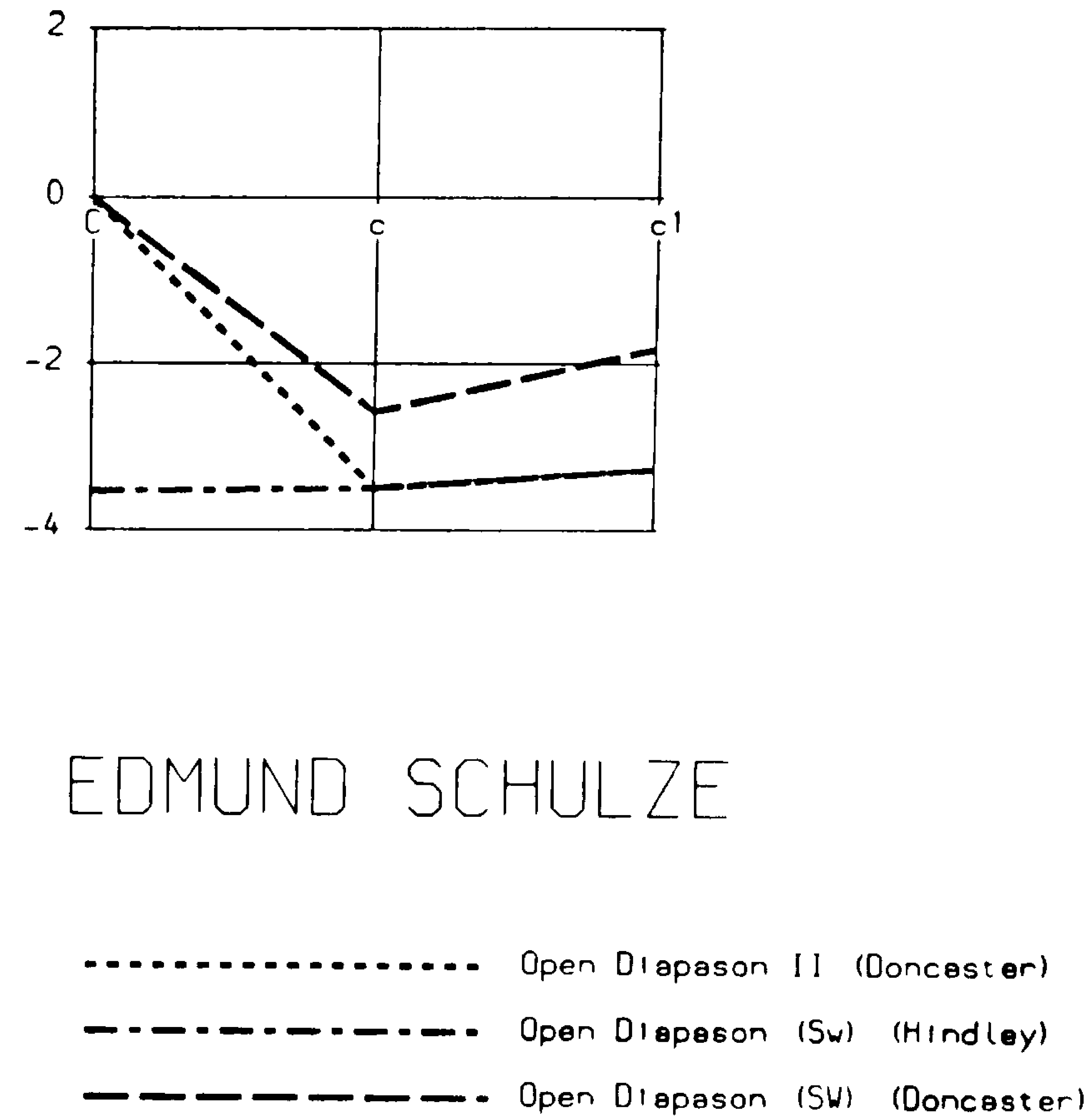
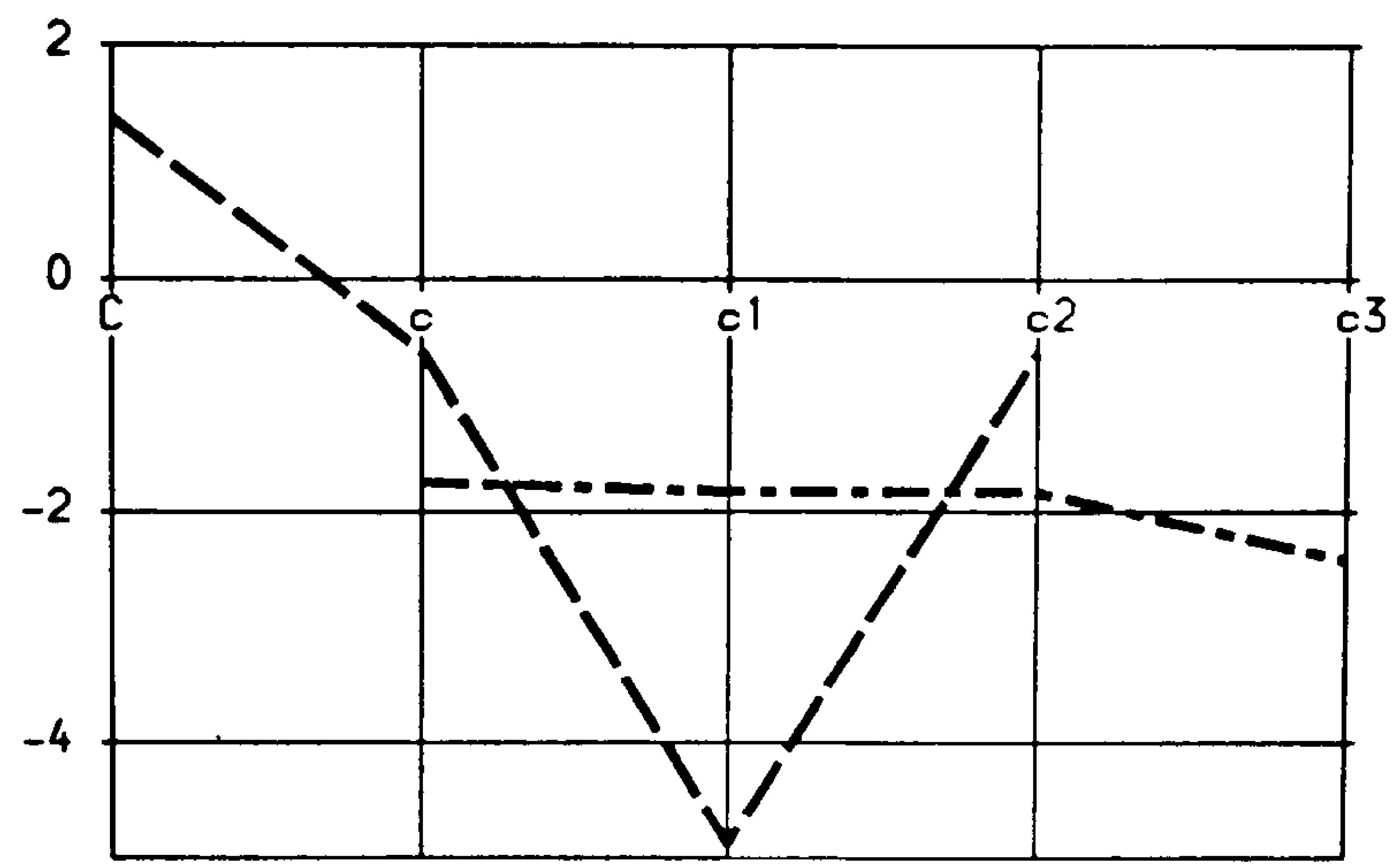


Fig. 20 (left) & Fig. 21 (right)



EDMUND SCHULZE

—·—·—·— Principal 4′ (Gt) (Doncaster)

— — — — Open Diapason No. 1 (Gt) (Doncaster)

Fig. 22

	C		c		c1		c2
Doncaster No. 2 (Gt.)	wood	-	79.4	16.3	47.7	16.2	28.6
Hindley No. 2 (Gt.)	118.5	17.2	73.0	14.6	41.3		-
Doncaster Principal 4' (Gt.)	85.7	15.9	50.8	16.0	30.2	15.2	17.5

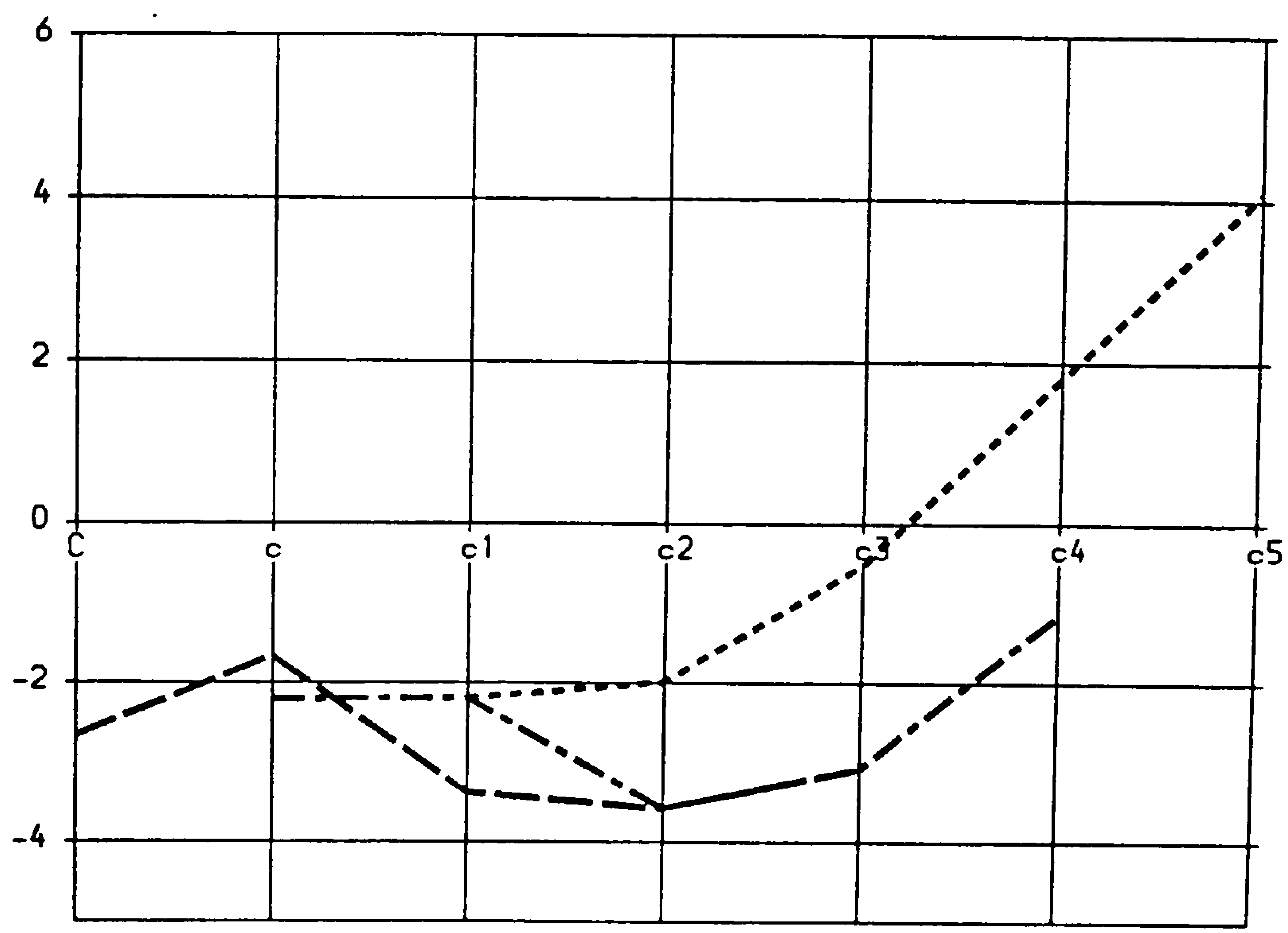
Wind-Pressures (in mm of wind)

St. Bartholomew, Armley,
Great and Swell 89.7 mm
St. Peter, Hindley,
Great and Swell 83.3 mm
Doncaster Parish church
Great 89.7 mm
Swell 86.5 mm

The other great German firm, Walcker of Ludwigsburg, also built organs in this country. An untouched example is to be found at the church of St. Felix, Felixkirk in North Yorkshire. The pipework is slotted throughout the organ (presumably a habit contracted from Cavaillé-Coll) including the Great Mixture III, which is slotted as far as f2 and contains (unusually) a tapered tierce-rank. This is quite contrary to the unslotted pipework of the Schulze firm. The scalings of the open, cylindrical great stops are given below.

St. Felix, Felixkirk, North Yorkshire. Walcker, op. 551.

	C		c		c1		c2		c3
		17.5		14.0		15.7		16.7	
Open Diapason 8'	138.5		86.0		47.5		28.0		17.0
mouth-width	102.0		60.5		35.5		21.0		14.0
mouth-height	28.0		17.5		11.5		7.0		5.0
		16.0		14.4		16.7		19.1	
Principal 4'	84.0		50.0		28.0		17.0		11.0
mouth-width	-		38.0		23.0		14.4		9.0
mouth-height	-		12.0		7.0		4.8		2.8
Fifteenth 2'		16.3		18.2		19.9		19.7	
(part of Mixture)	50.0		30.0		19.0		12.5		8.2
mouth-width	38.0		24.0		15.0		10.0		6.3
mouth-height	11.5		7.0		4.5		2.5		2.0



ST. FELIX, FELIXKIRK (WALCKER).

.... Fifteenth (Gt. Mixture)

-·-·-·-·-·-·- Principal 4′ (Gt.)

— — — — — — — Open Diapason 8′ (Gt.)

Fig. 23

The scale-graph at figure 23 shows clearly that these scales move with only small-scale variability about the Toepfer norm. These scales are not constant in the way that those of the Schulze firm are, but represent changes in scaling-ratios between the three recommended Toepfer scales, namely 1:2.66, $1:\sqrt{8}$, and 1:2.519.

'Father' Henry Willis

The scales for the Great stops in the organ at St. Luke's Chapel, Winterton Hospital near Sedgefield in County Durham are shown below. This instrument, although it has not been properly identified, as the hospital minute book is missing,[70] is unmistakably a 'Father' Willis instrument,[71] identifiable from, amongst other features, stop-nomenclature and console-design. The instrument was probably built as a residence organ in the 1870's, housed, as it is, in a diminutive classical case,

> 'It is not yet possible to be more specific about its origins - where it came from and who transferred it remain problematic.'[72]

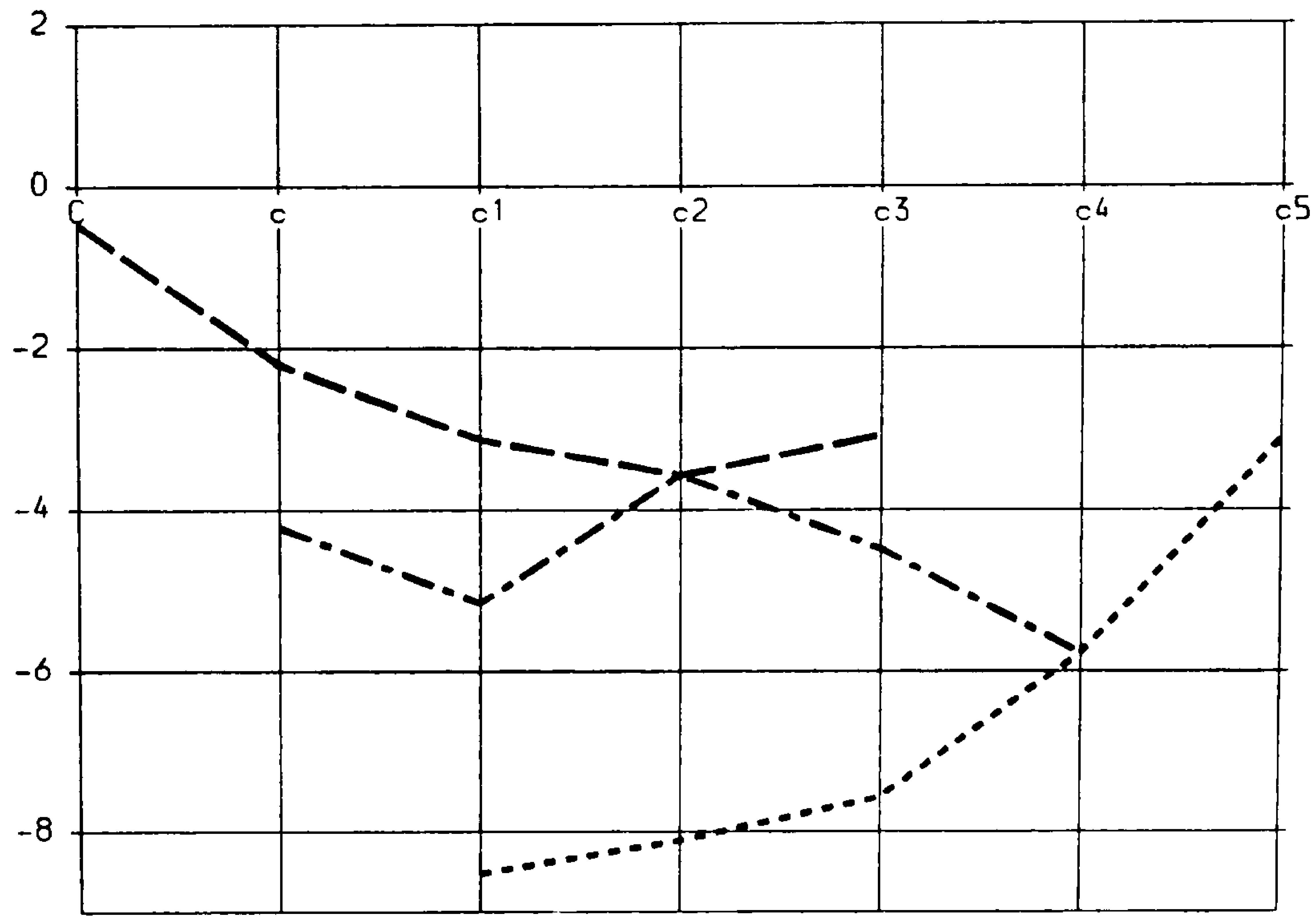
It seems possible that this instrument is the same one referred to by Thomas Henry Collinson in his diary[73] who records that on August 4th, 1875:

> 'I went to Vincent's this afternoon, saw Mr. V's large organ (Willis), played duets at night till 1.30am'[74]

Mr. Vincent being an organ-builder in Sunderland, and a successful imitator of Schulze's organs.

'Father' Willis (1870's) St. Luke's Church, Winterton Hospital, Sedgefield, Co. Durham

STOP NAME	C		c		c1		c2		c3
		14.0		14.9		15.4		16.7	
Gt. Open Diapason 8'	152.4		84.0		48.0		28.0		17.0



´FATHER´ WILLIS, WINTERTON HOSP.

Fifteenth 2´ (Gt)
Principal 4´ (Gt)
Open Diapason 8´ (Gt)

Fig. 24

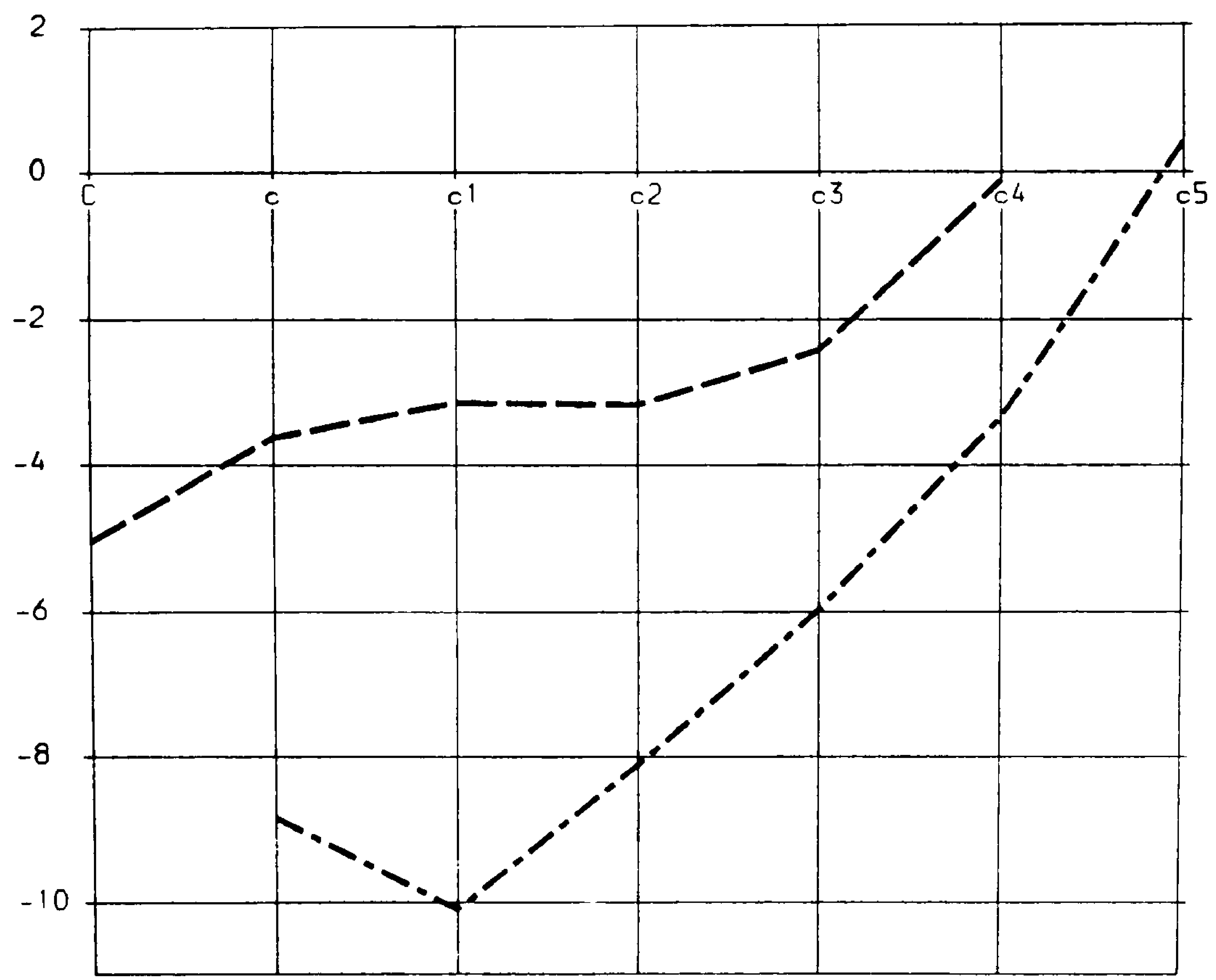
Gt. Principal 4′	77.0	14.9	44.0	18.4	28.0	14.9	16.0	14.5	9.0
Gt. Twelfth 2 2/3′	34.0	15.7	20.0	19.3	13.0	17.1	8.0	17.7	5.0
Gt. Fifteenth 2′	38.0	16.6	23.0	16.8	14.0	18.8	9.0	20.5	6.0

The 'Father' Willis scales are fairly unadventurous and do not display as much variety as the Harrison and Harrison scales of 1895 (see below) taken from the organ at Sherburn Hospital Chapel, Durham.

They are very similar to the Wilkinson scales which follow. The 'Father' Willis Open Diapason 8′ following the ratio of 4:7(1:1.75), the fifteenth more or less following the ratios 3:5 (1:1.66) and then 1:1.63 in the treble, with a fractional widening in the last octave (see fig. 24).

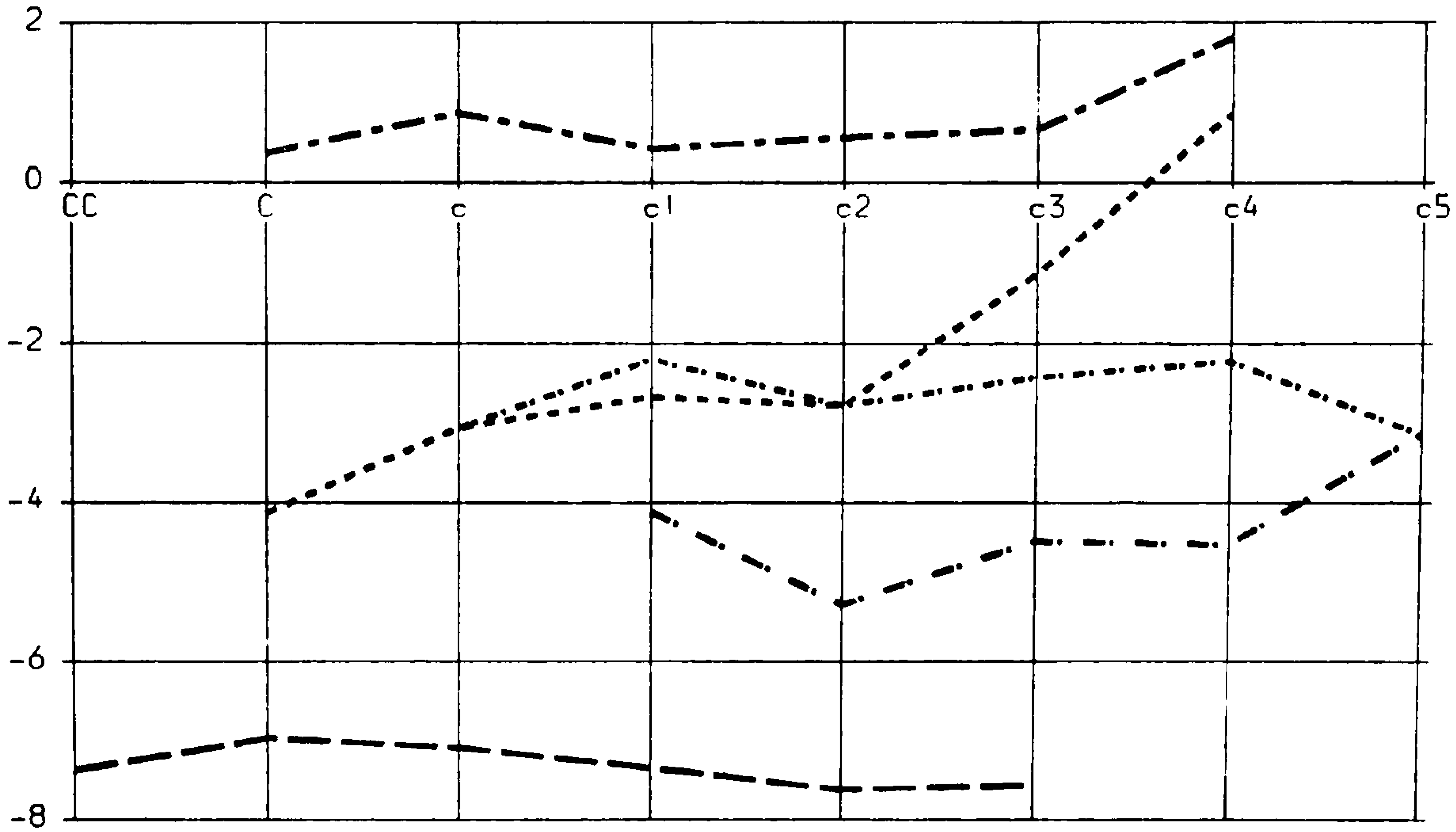
Wilkinson & Son Ltd.

The diapason scalings for the Preston Public Hall by Messrs Wilkinson and Son, of Kendal (1882) are listed below.[75] Thomas Wilkinson is typical of a small local firm building modest-sized organ. This four-manual instrument for Preston Public Hall (then the Corn Exchange) resulted in enlargement of the firm although the Preston organ was the largest one that the firm built[76] and it represents the last years of mature tonal design before the onslaught of the 'new' ideas on tonal design which became common at the turn of the century. This organ is complete to two mixtures on the Great (Sesquialtera IV and Mixture III) with Pedal and Swell Organ mixtures.[77] The scale charts of Swell and Great Organ are clearly shown revolving around the Toepfer $1:\sqrt{8}$ scale halving on the sixteenth-step, the scales being



PRESTON PUBLIC HALLS, WILKINSON, 1882.

Fig. 25



PRESTON PUBLIC HALLS, WILKINSON, 1882.

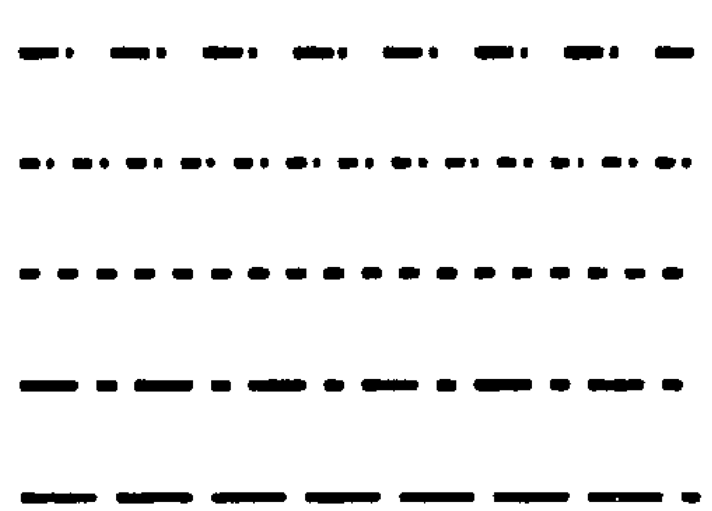


Fig. 26

virtually parallel to the x axis. These scales are plotted in figures 25 and 26.

PRESTON PUBLIC HALL

Great Organ	C		c		c1		c2		c3		c4
Double Open Diapason 16′	190.0	16.6	115.0	15.8	68.0	15.7	40.0	15.6	23.5	16.1	14.0
Open Diapason 8′	158.0	16.7	96.0	15.4	56.0	16.2	33.5	16.1	20.0	17.7	12.5
Horn Diapason 8′	130.0	17.6	81.0	16.6	49.0	15.9	29.0	18.5	18.5	19.2	12.0
Principal 4′	81.0	17.2	50.0	15.3	29.0	16.5	17.5	16.3	10.5	14.9	6.0
Twelfth 2 2/3′	57.0	15.2	33.0	15.1	19.0	16.6	11.5	19.5	7.5	20.5	5.0
Fifteenth 2′	46.0	14.6	26.0	17.1	16.0	16.0	9.5	18.1	6.0	17.7	3.75
Swell Organ											
Violon Diapason 8′	125.0	18.1	79.0	16.7	48.0	16.0	28.5	17.1	17.5	19.8	11.5
Octave Violon 4′′	63.0	14.5	35.5	19.2	23.0	19.5	15.0	20.5	10.0	23.3	7.0

James Jepson Binns

It is interesting to note that in many of the scales quoted by British builders after Edmund Schulze, there is a tendency to start the lowest C of the 8′ open diapason at large diameters (as large as 190mm [J.J.Binns] and a scale of 152.4mm for bottom C at Winterton Hospital for a house organ) and then to narrow the diameter considerably through the bass and tenor range before it widening again.

JJ Binns(1902, op.334), St. George's Congregational Church, Hartlepool.

STOP NAME	C		c
Gt. Open Diapason I 8′	190.0	10.0	82.6

Gt. Open Diapason II 8′	158.8	11.3	76.2
Gt. Principal 4′	76.2	20.5	50.8
Gt. Flautina 2′	44.5	14.8	25.4

JJ Binns, Hartlepool Independent Church (1919).

STOP NAME	C		c
Gt. Open Diapason I 8′	165.1	12.7	85.7
Gt. Principal 4′	73.0	11.3	34.9

JJ Binns, Hartlepool Town Hall, (Op. 1027)

STOP NAME	C		c
Gt. Open Diapason I	139.7	17.0	85.7

This trait is particularly noticeable in those scales by J.J. Binns (curators of the Schulze organ at Armley) whose progressions often begin halving on the 10th-or 12th-step in the lowest octave, a ratio of about 1:2 between the c's. This may also be observed in the old number 1 Great Open Diapason rank at Doncaster (1862) before the widening of the diameters begins. It seems that in later years the Schulze firm reverted to a freer approach to scaling, but only in terms of a change from constant to the fixed-variable type. Klotz[78] has commented that Schulze used broader scales in the bass register, the dimensions of which could not be continued in the treble-range in a constant scale as wide dimensions in the treble-pipes meant that obtaining diapason tone from such wide pipes was difficult. The change from constant to fixed-variable scales (of however crude an approach in comparison to examples of such scales in much earlier organs) would seem to have been forced upon the organ-builders when such wide scales became 'tasteful'. Thus the introduction of (or, in truth, reversion to) fixed-variable scales came not from a didactic notion of reform in scaling practices, but from the lust for power in instrument design. The development of the leathered diapason meant that constant scales could be used with such powerful diapasons where the tone was forced and timbre controlled by the application of leather to the upper lip. Had Hope-Jones developed this type of pipe earlier, there may well have been no change in scaling practices.

Harrison & Harrison Ltd.

This freer approach to scaling (albeit of the logarithmic type) resulted from imitations of the Schulze scales but with wider diameters than Schulze ever used and perpetuated because of the gravity of sound the organ receives in the pedals through the Great to Pedal coupler, a gravity of sound prevented from generating a 'nice thick gravy to smother the wrong notes'[79] by the time the scale reaches the middle register of the stop by the process of narrowing the rank. Such scales can be seen in a less exaggerated form in those by the firm Harrison and Harrison for the organ installed in Sherburn Hospital Chapel in 1895.

Harrison and Harrison (1895), Sherburn Hospital, Sherburn, Durham.

STOP NAME	C		c		c1		c2		c3
Gt. Open Diapason 8'	146.0	13.5	79.0	16.7	48.0	16.5	29.0	30.1	22.0
Gt. Principal 4'	73.0	14.4	41.0	16.8	25.0	30.3	19.0	21.9	13.0
Gt. Fifteenth 2'	38.0	15.2	22.0	26.1	16.0	17.7	10.0	16.3	6.0

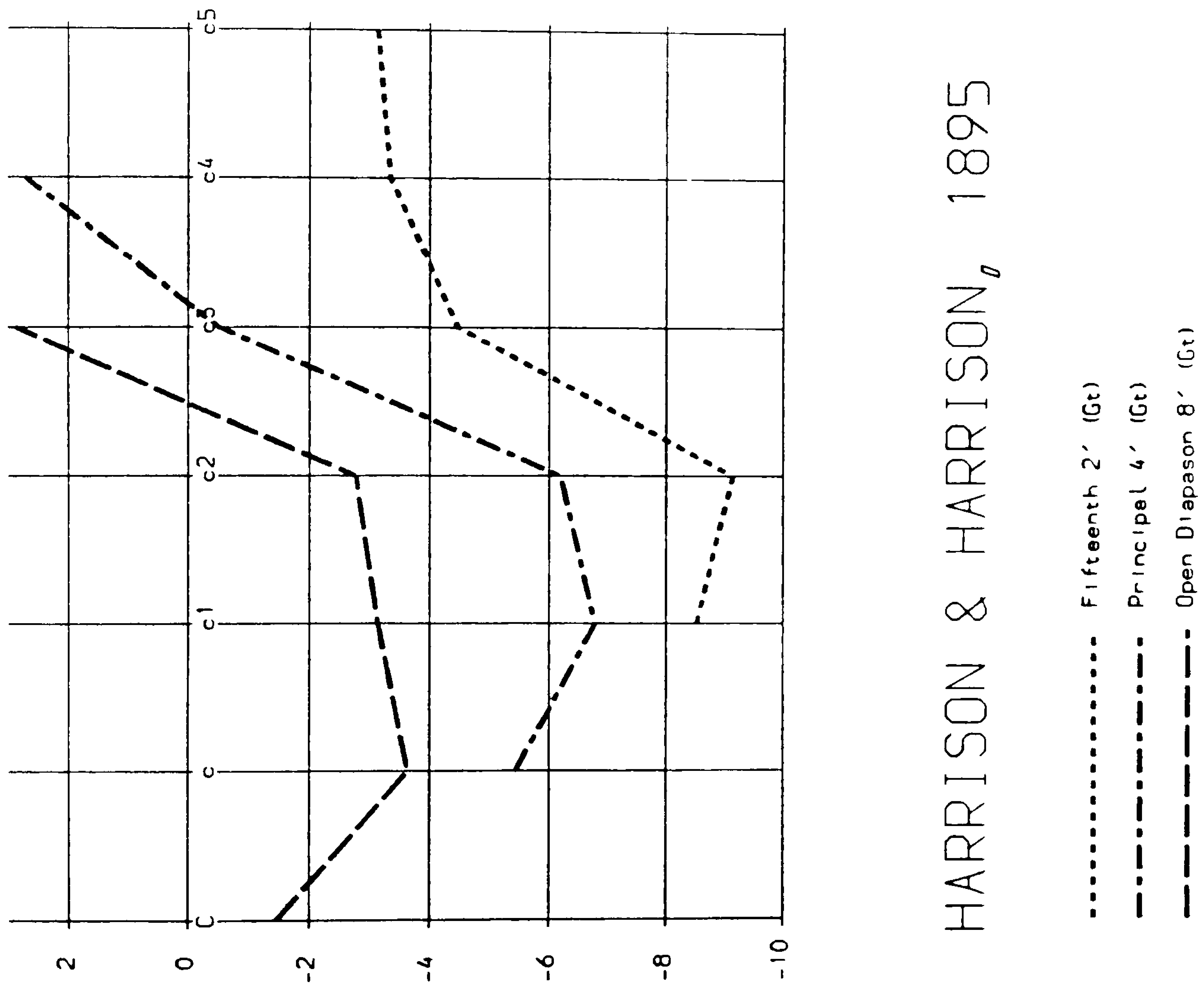

HARRISON & HARRISON, 1895
Fifteenth 2′ (Gt)
Principel 4′ (Gt)
Open Diapason 8′ (Gt)
2
0
-2
-4
-6
-8
-10
C
c
c1
c2
c3
c4
c5

Fig. 27

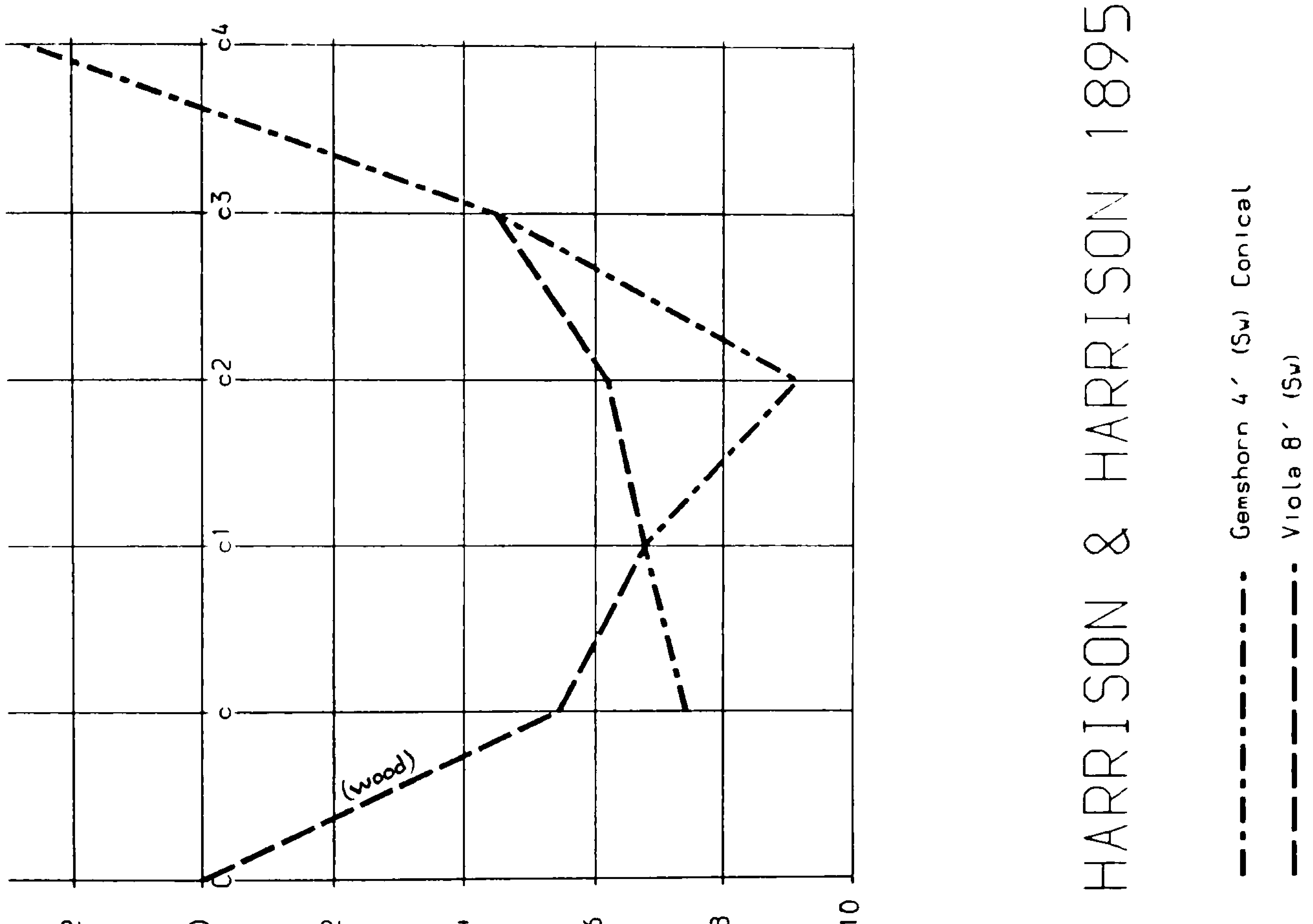

HARRISON & HARRISON 1895
Gemshorn 4′ (Sw) Conical
Viola 8′ (Sw)
(wood)
C
c
c1
c2
c3
c4
2
0
-2
-4
-6
-8
-10

Fig. 28

Sw. Viola 8′	wood		73.0	14.4	41.0	16.8	25.0	18.6	16.0
Sw. Gemshorn 4′ (cylindrical)	67.0	16.9	41.0	13.4	22.0	26.1	16.0	40.1	13.0

Such scales, although using only Toepfer progressions are more inventive in that they change their progression not only more frequently, but over a wider selection of halving-ratios than the Willis examples. This can be seen in the two sets of scales from this organ at figures 27 to 28. In the same decade, T.C. Lewis in his organ at Southwark Cathedral (1896) used scales halving on the 17.5th-step and the 14th-step for his large and small open diapasons respectively as well as Schulze-type wood basses for his Swell open diapason.

J.J. Binns apparently did not discern the true nature of Schulze's scales until 1921 despite rebuilding the Armley Schulze Organ in 1905. He wrote to the Rev. Noel A. Bonavia-Hunt:

> 'I have just come across something in the Schulze organ at Armley that will surprise you... to my surprise I find all the great, that is, open 16ft., open 8ft., principal 4ft., twelfth, fifteenth and mixture five-ranks are all the same scale as the open 8ft. What do you say to this? I guess this is an eye opener to most folks. And all are voiced so as to get every bit of tune out of each pipe'.[80]

Of course Bonavia-Hunt knew this, he wrote about it in 1905. It seems quite absurd that Binns, who had won respect and contracts as an organ-builder as a result of his ability to copy Schulze's pipework, should not discover this fundamental principle of Schulze's chorus-structures until close to the end of his life.

The scales employed by the Schulze firm are typified in the examples shown. The mixture work and upperwork have similar scales, and this is the feature which gives these instruments their power. The 1851 exhibition, in presenting a wealth of organs helped initiate the so-called 'battle of the organs',

> 'a major "cold-war" between the Willis ideal of the rich, reedy orchestral ensembles and the rival school of the dominating flue-choruses, pushed in power and scale to their artistic limits and beyond the limit of common usefulness'[81]

Disciples of Edmund Schulze

The many disciples of Schulze included Lewis, Binns, Vincent, Pendlebury (curator of the Schulze organ at St. Peter's, Hindley), Abbot and Smith, Jardine and Forster and Andrews, Lewis' work being almost entirely based on the scales and voicing used by his German master.[82] Lewis is reputed to have said of Schulze:

> 'He is a fine artist, and those who criticise him are not worthy to clean his boots'.[83]

Lewis must have been aggravated by Cavaillé-Coll's feeling that Lewis' work had more affinity with his own than did that of Willis.[84]

Bonavia-Hunt relates how H.S. Vincent (of Sunderland) reproduced the Tyne Dock Open Diapason No. 1 in several organs[85] and that Vincent, not content with reproducing pipes that could be exchanged for Schulze's originals, reproduced the entire soundboard.[86] Apparently T.C. Lewis and E.J. Hopkins visited Schulze's organ at Doncaster but could not voice the 'barrow load' of diapason pipes they took with them to match the voicing skill of Schulze.[87] Edmonds writes:

> 'I have in fact heard the tone recaptured once, in an open diapason made and voiced by R.W. Davidson...on a soundboard specially designed by Bonavia-Hunt. It is impossible to describe the sound in words, reminiscent of a 'cello, yet clearly an open diapason; far from heavy, though a bit loud - but as Davidson said, the tone could be expressed at any level down to dulciana'.[88]

Lewis complained that Schulze's work was 'hacked in name only' but 'unfortunately in name only'.[89] At one time it was practically a necessary pre-requisite to be able to copy the work of Schulze; another account tells how Dr. William Spark, sometime organist of Leeds Town Hall, challenged J.J. Binns to construct a 'Schulze-type' pipe and to set it in with the originals, the point being that if Spark could not detect the pipe he would give Binns a contract to make him a house organ.[90] Schulze has been unjustly criticised in the same way that Toepfer has been, but neither can be blamed for the poor quality instruments of their incompetent imitators. Although Schulze did bring hitherto unknown stridency of the diapason-chorus to this country, (principally an account of the continuation of that tonal stridency throughout the upper work, mostly dictated by the large scales continued in the logarithmic progressions throughout the mixtures, and also because of his open-foot voicing techniques [91]), he was simply a product of what was happening in Germany at that time.

> 'Excessive power was a mask of the German romantic organ, and you can still hear some of the world's most brutal organs in that country, some of them quite modern. What Schulze did was to produce open diapasons of

> a unique tone, with upperwork to match. It is really the tone which is the hallmark of Schulze, and that not only in the open diapasons. The blend of his choruses was a revelation, but he customarily expressed them in a greater level of sound than had been customary here. This made them perhaps more impressive than generally useful.'[92]

The English organ had begun to show Germanic tendencies by the 1851 Exhibition, adopting the so-called 'CC-Pedalboard' and supplying 10 2/3' and 5 1/3' stops in the Pedal and Great Organ of such instruments. Even by 1855 E.J. Hopkins was forced to take note of recent scaling developments,

> 'The vast disparity of breadth in proportion to length between English and foreign Organ Pipes naturally suggests three questions-(1) how have pipes of such huge bulk come into use? (2) What may be may be their effect? and (3) is that effect such as will justify the appointment of so much space, not easily spared, to their accommodation?'.[93]

The missionary zeal of religion, particularly with the growth of the churches of the dissent and the new churches erected as a result of the industrial revolution, meant that hundreds of new churches were being built in the North-West of England. Such large spaces needed filling and evidently the large-scale diapason found favour with Lancashire and Yorkshire men. Instruments erected by Hill at Beverley[94] and Selby were filled with such large diapasons because the resident organists desired such additions, contrary to the wishes of that organ-builder.[95]

By the turn of the century, partly in the hands of Robert Hope-Jones (1859-1914), who, despite having a company lasting between 1889 and 1903, managed to reek havoc in the organ-building world, pipe-scales were pushed to ridiculous extremes. Audsley, a great disciple of Edmund Schulze, reports in 1905 that the scales commonly range between 7- and 5-inches (177.8mm and 127mm) and that

> 'The largest scales seem to have been used by the English builders, but these have, in artistic work, seldom exceed 6.75 inches [171.45mm]. The German builders appear to have fixed the maximum diameter for the CC [C] PRINCIPAL pipe at 6.25 inches.'[158.75mm][96]

Schulze exceeded that at Doncaster in his Open Diapason I, and in 1910, Hill, Norman and Beard added another, larger, open diapason with a lowest metal pipe (G) of 146.1mm and C of 114.3mm. The Great Open Diapason in Durham Cathedral (Harrison and Harrison, 1935) represents the outer limits of diapason pipe-scales, with a colossal diameter at 8' C of 202mm.

Hill, Norman and Beard (1910), Doncaster Parish Church.

STOP NAME	C	c		c1
			15.0	
Gt. Open Diapason I	Wood (G=146.1)	114.3		63.5

Harrison and Harrison, (1935), Durham Cathedral.

STOP NAME	C		c		c1		c2		c3
		14.1		14.7		15.4		16.7	
Gt. Open Diapason I 8'	202.0		112.0		63.5		37.0		22.5

Logarithmic scaling became the accepted norm. Bédos became scorned. Audsley writes

> 'Dom Bédos, in his ponderous treatise, gives numerous scales set out full size. There seems to be some system followed in the formation of these scales, but it is so erratic that we have failed to discover it'[97]

and recounts that

> 'Toepfer tried the scales given by Dom Bédos,

> and found them very unsatisfactory. This can readily be understood under the light of modern experience'.[98]

Audsley is correct, however, in his assertion that prior to Robertson's work on organ-building, no works had appeared in English which concern themselves with pipe-scales. The exhaustive work by Hopkins and Rimbault[99] devotes but a few pages to the question of scales, and other than quoting various diameters used to start progressions,[100] there is no word at all about *which* progressions, although he mentions the 'Diapason-measure' which if exceeded yields the 'Cornet-scale and tone'. To make this clearer he gives an example:

> '...if a Pedal Principal were made to a much-increased measure, so that its middle C' Pipe [c] (2 feet) [61.38cm] were to be advanced from about 2 inches [51.3mm] to nearly 2.5 inches [54.1mm] in diameter, it would produce a tone, powerful and broad, indeed. but utterly unlike that of a member of the Diapason-work'.[101]

The following scales appear in Hopkins and Rimbault for the Great Organ Bourdon 16' (stopped wood) on the 1851 exhibition organ by Edmund Schulze, resited at the Exchange Room, Northampton,[102] and a Lieblich Gedackt (stopped wood) scale for 16-foot tone examples of which

> 'occur on the upper Manual of the Organ at The Exchange, Northampton'[103]

Bourdon 16'

Note	Depth	Width	Area	Note number
CC	155.6	117.5	18283.0	1
GG	120.7	82.6	9969.8	8
C	92.1	71.4	6575.9	13
F	77.8	58.7	4566.9	18
C	55.6	42.9	2385.2	25
bb	38.1	28.6	1089.7	35

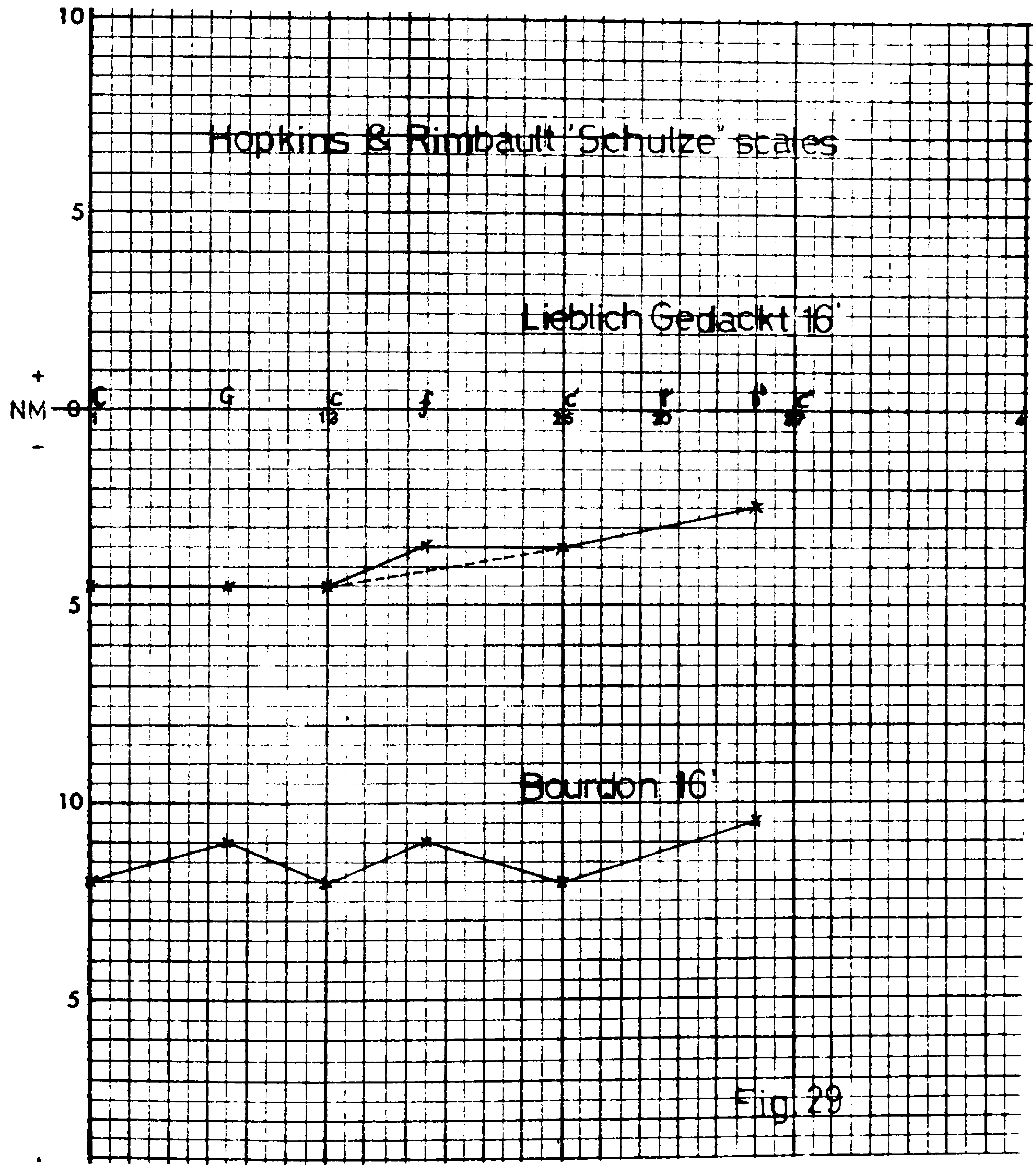
Lieblich Gedackt 16′

CC	127.0	85.7	10883.9	1
GG	95.3	68.3	6509.0	8
C	76.2	55.7	4244.3	13
F	63.5	42.9	2724.2	18
C	47.6	34.9	1661.2	25
bb	31.8	12.7	403.9	35

These scales are not characteristic of Schulze. Audsley is forced to point out that the scale for the Lieblich Gedackt given by Dr. Hopkins is

> 'remarkable for its irregularity: each octave seems to have a ratio of its own, if ratios have been used at all in its formation. It approaches most closely to the standard ratio of 1:2.519'[104]

or whose half-measure falls on the 18th-step or 19th-note. Hopkins states that both the Lieblich Gedackt and Bourdon scale reach their half measure on the 'interval of an eleventh'[105] which, whilst being consistent which Schulze's use of logarithmic progressions, is not the same as the scale measurements given. Furthermore, the Choir organ Lieblich Gedackt 16′ on the Exchange Room organ by Schulze only had pipework made as far as Gamut G (G). Whilst Hopkins does not categorically state that the scale he cites is from the Northampton Exchange Room organ, he states that examples of them are to be found on that organ.[106] Presumably Hopkins measured some stop by Schulze to cite the example, but the 16′ CC is a fictitious measurement for Northampton and Hopkins indicates that pipework ceased at Gamut G.[107] In the absence of confirming evidence (the organ is no longer extant)[108] the possibilities are that Hopkins measured some other Schulze organ,[109] or that Schulze used older pipework for these scales and adopted them to conform as closely as possible to the ratio halving on the eighteenth-


Hopkins & Rimbault 'Schulze' scales
Lieblich Gedackt 16'
Bourdon 16'
NM
10
5
0
5
10
5
C
G
c
f
c'
f'
b'
c''
1
13
25
Fig. 29

step. It is also possible that Hopkins measured the notes incorrectly. The measurement for F in the Lieblich series, for example, if one note narrower would conform to the scale almost exactly, (see dotted line in figure 29).

It is not clear whether Hopkins knew of the method of scaling logarithmically. He does note that

> 'It should be mentioned that the Pipes of a Stop made to the German scale just refered to, [i.e., in Northampton] decrease in size or bulk more gradually than is common with English scales.'[110]

and that the half-measure on the interval of the eleventh 'from whence the calculation commences'[111] is the reason for the 'remarkably full tone'.[112] Does Hopkins mean Toepfer's 'calculation' or is this simply a reference to determining the scale through conventional methods of scale-calculation. in other words, by a Dom Bédos-type diagram? No conclusion may be drawn at the present time.

It is currently fashionable to sneer at the excesses of the organ from after the turn of the century, and in particular the 'factory organ'. To put these instruments in a clear historical perspective it is important to remember that there have been poor organ-builders in every century. The fact that a multitude of new organ-builders sprung up is due to sociological and economic factors rather than to the farcical suggestion that it was as a result of the ease by which builders could work from Toepfer's book. Certainly in England there was never an equivalent of the works of either Bédos, Hamel or Toepfer, the first weighty tome in English dealings comprehensively with the organ its 'history and construction' and its 'structure and capabilities'[113] was Hopkins and Rimbault's work of 1855. There are two other English treatises of significance, the so-called 'First English Organ Treatise'[114] dating from the 1690's and being in the hand of James Talbot of Trinity College, Cambridge, Professor of Hebrew there between 1699 and 1704. This does contain some technical information but lies outside the scope of the present work. The other is a late 18th-century treatise by Jonas Blewitt (1757-1805) published about 1790.[115] This work is expressly directed towards the 'rendering of Theory and Practice subservient to mutual elucidation'[116] and contains no scaling information.

It would seem that the development of Toepfer's logarithmic scales in England was principally the result of the copying of Schulze's scales, particularly if the experience of J.J. Binns is taken into consideration. The growth of the industrial revolution affected all new businesses and organ-building was not exempt from that. There is no accounting for whims and changes in taste from generation to generation. Few builders at the time of Hope-Jones, for example, were reluctant not to copy his huge-scales and small-scales for string-stops, diaphones, electric actions and consoles etc. Hope-Jones was not an unfortunate mistake in the history of the organ-building world, he was given birth by the discerning tonal palette of late Victorian England. These 'unsociable sonorities' (as Niland calls them) of this 'fin-de-siècle eminence grise'[117] were the sociable sonorities of the day. Percy C. Buck (1871-1947) worked in conjunction with Hope-Jones at the Victoria Rooms, Bristol, and recommended him to the 'vestry' of St. John's Cathedral, Newfoundland,[118] amongst other places. Buck wrote in 1912

> 'The most general failing of organs is admittedly the inadequate supply of 8' stops. 'All top and bottom' is the frequent verdict one passes after listening to shrill principals and fifteenths coupled to a booming pedal diapason. On the Great Organ especially this is noticeable..... Room could be found for them by discarding the whole tribe of mixtures, sesquialteras and twelfths, for which an ever increasing number of organists can find no justification whatever. A soft mixture on the swell can give a curious and gratifying tingle to a chord, but neither the laws of acoustics nor the sensitiveness of the human ear, will, it is hoped, tolerate much longer the existence of 'mutation' stops on the Great Organ'.[119]

Buck was also the author of a work on musical acoustics,[120] and thus, in his day, spoke with authority both as Professor of Music in the University of Dublin and Director of Music at Harrow School.

The treatise of F.E. Robertson in 1897 followed by Audsley's mammoth treatise of 1905 made available in English the ideas of Toepfer and some very detailed study of the work of Edmund Schulze and his better imitators. Both Audsley and Bonavia-Hunt sought ideal organ-tone as if a quest for the Holy Grail,[121] loathing the pipe-slotting of Willis contracted from France and in particular Aristide Cavaillé-Coll, calling it

> 'a pernicious habit which for nearly half a century vitiated the pure tone of the King of Instruments, and infecting it with the taint of 'horniness''.[122]

Cavaillé-Coll had slotted his pipes to prevent lazy tuners 'pinching' the pipes when tuning. Like so many aspects of organ-building, this became an issue in its own right.

The lust for power in diapason pipe-speech, grossly exaggerating the scales, deep nicking of the languid (the antithesis of Schulze's 'nicking languids like a hair'),[123] high cut-up and narrow mouth (as much as 1/5), leathering of the upper-lip, increased wind-pressure, and closure of the toe-hole (open-feet had characterised Schulze's work), resulted in loss of conventional organ pipe-speech and the development of a rather affected, and refined tone, typical of the first decades of this century. Bonavia-Hunt has commented that

> 'the desire for refinement, dignity and foundation is characteristic of the British race, and it is certainly true that these qualities were the most conspicuous feature of the early English diapason'.[124]

Herbert Norman remembers that

> 'Low pressure, low cut-up, un-nicked voicing was not unknown and the merit of thin rich metal was no mystery. As a student voicer in 1919, I was shown a prized three octaves of Father Smith chimney flutes, just a nick in each corner and a breath of pressure through an unconed foot. We vied with each other to make and voice copy pipes. But nobody wanted it, it was not 'refined''.[125]

In such days as these, the large organ factories employed as many as 300 craftsmen, specialists in voicing gambas, flutes, diapason upperwork and mixtures, reeds, violes and keen strings. These 'factories' were hard working labour forces who took pride in their craftsmanship, there was never any 'crass commercialism' in the big firms. Organ-builders were subject to the convention and misconceptions of the age:

'In such a commercial climate, the player was a professional, the organ-builder a tradesman, with all that that meant in the society of those days. Stepping out of line was risky; refinement, however dull, was the demand. In some stop lists in Dr. Hill's order book of 1920 the Great Organ Diapason was often specified as 'of heavy metal and devotional tone'!'[126]

There were few builders of this age who took no notice of acoustical considerations within the tonal constraints available to them. A master scale-book at Wm. Hill and Son and Norman and Beard Ltd., set out the scale-sizes for every conceivable stop listed according to requirements of acoustic and building size of the job in hand.[127] All such scales set out for ease of construction on scale-rods which could be used in different organs. These are common features of organ-building today, and no organ-builder works his scales out without taking into consideration the acoustic conditions. Now that the emphasis is beginning to shift (in this country) away from the constraints of constant logarithmic scales, the organ-builder needs to examine criteria for using certain diameter progressions in certain situations.

The German organ-building scene had started to reform. New instruments were built to old specifications, but the results were cacophonous Mahrenholz relates that during the 1926 Freiburg German Organ Congress

> 'a lively discussion arose about whether the old master organ-builders kept strictly to "sacred numbers" in calculating organ scales or had the full freedom of their "artistic intuition". The Congress director, W. Gurlitt, indicated that an answer to the problem was urgently needed.'[128]

As a result of this request, Mahrenholz compiled his work on pipe-scales which was published in 1938. Instruments were then built which sounded marginally better. This was naturally the case when pipe-scales were copied but not the voicing techniques. It has taken many years to come to any understanding of the voicing techniques of the older master-builders and much work is still going on. It is only recently that any concerted effort has been made to establish exactly what the early English builders were doing with their pipes. The invasion of the half-thought-out ideas of open-foot voicing in conjunction with electro-pneumatic action produced barbaric sounds and explosive pipe-speech of the so-called neo-classical organ. Continental builders were much further advanced by the time such organs were being manufactured by British builders. Reduced wind-pressure, slider-chests and mechanical key-actions returned to organ-building, together with a deeper understanding of the intrinsic function of proper case-work in organ-design. This latter development took root too late to stop the many neo-Holtkamp, functional case-designs from sweeping across America and England, despite the fore-sightedness of James Dalton with the Frobenius organ (a pioneering example for this country) at Queen's College Chapel, Oxford in 1965.

Tragically, the political situation in Germany meant that the work of the reformers, particularly that of Marenholz in the field of pipe-scaling, took much more time to reach English ears than would have been the case under normal political conditions. In the aftermath of the Second

World War, hundreds of new churches were erected in Germany giving rise to hundreds of new organs. The fact that organs were at the bottom of the list for 'ecclesiastical fittings' meant that cheaper organs were supplied, effectively returning to the situation prior to the war. The *Orgelbewegung* took retrogressive steps.

Significant developments in the scaling practices of British Organ-builders

In England, Ralph Downes was the sole reforming influence with his new schemes for Brompton Oratory (1954) and at the Royal Festival Hall (1954). The opening rectial at the Royal Festival Hall caused a *furore*; acidic letters appeared in many musical journals from people least qualified to comment upon such matters. The fact was that the auditorium at the Hall was designed to have virtually no ambience at all, the desired effect being that performances might sound as they did in the open air. How such a barren acoustic ever came to be designed or constructed as a music hall will remain a mystery to many musicians. Despite the introduction of electronic reverberation in the Hall, the acoustic is still a killing influence on the organ. Few instruments could have held their own is such poor acoustic conditions, a task for the organ-builders. Harrison and Harrison, made much more difficult by the problems of trying to build an organ using completely new voicing and scaling-methods - methods new to the builders. It seems clear now that Downes was still very much in the dark about such designs at the time, particularly judging by the rapid changes in tonal outlook that the organ's design-stages underwent in such a short space of time. Even as recently as 1969, Lawrence Phelps wrote of the English organ revival

'...reform has been so slow in developing as to hardly be worth mentioning. Even today there is little evidence of a real movement toward general improvement. Although Ralph Downes...has fought a valiant battle for organ reformers, his efforts have actually produced very little, the work at the Brompton Oratory and the Royal Festival Hall being the most significant. Downes is a reformer without clear convictions, and thus his work serves more to confuse his countrymen than to lead them.'[129]

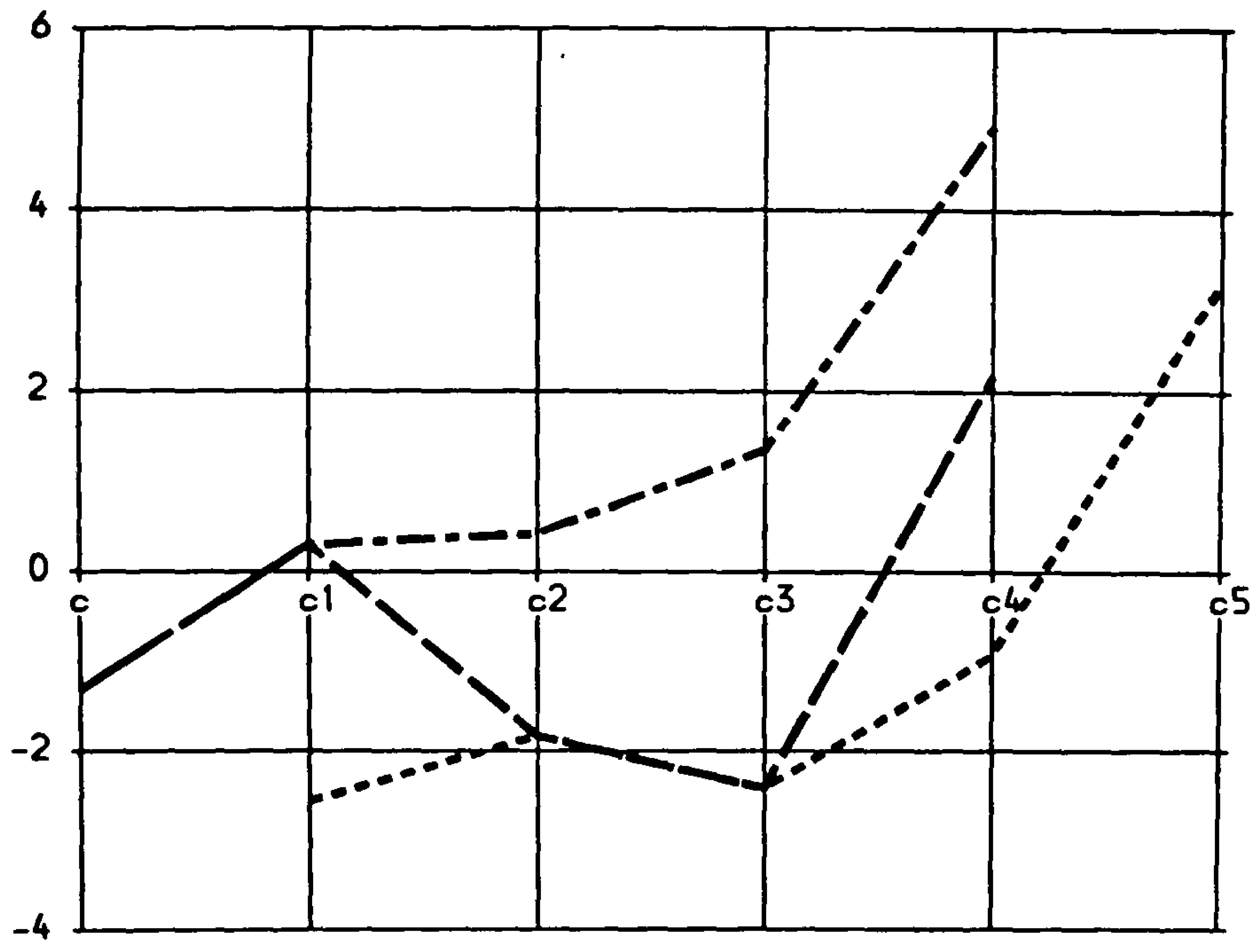
Williams has driven the message home very clearly:

'The Festival Hall's 103 stops provide German Flutes, Anglo-German choruses, French reeds and other elements carefully calculated to allow many different types of organ music. But the size of the organ, the sprawling, largely un-encased construction and electro-pneumatic action make it impossible for either player or listener to achieve true sympathy with any musical style other than the town-hall transcription, of which presumably it had hoped to sound the death-knell.'[130]

The Royal Festival Hall organ was the first departure from what had become 'traditional' (nineteenth-century) scaling-practices.[131] Downes advertised the organ's flue-stop scales as being individual and variable. Only nine of the organ's stops were constructed according to Harrison and Harrison's normal scaling-practice. The scales were not exact copies of existing work by other organ-builders,

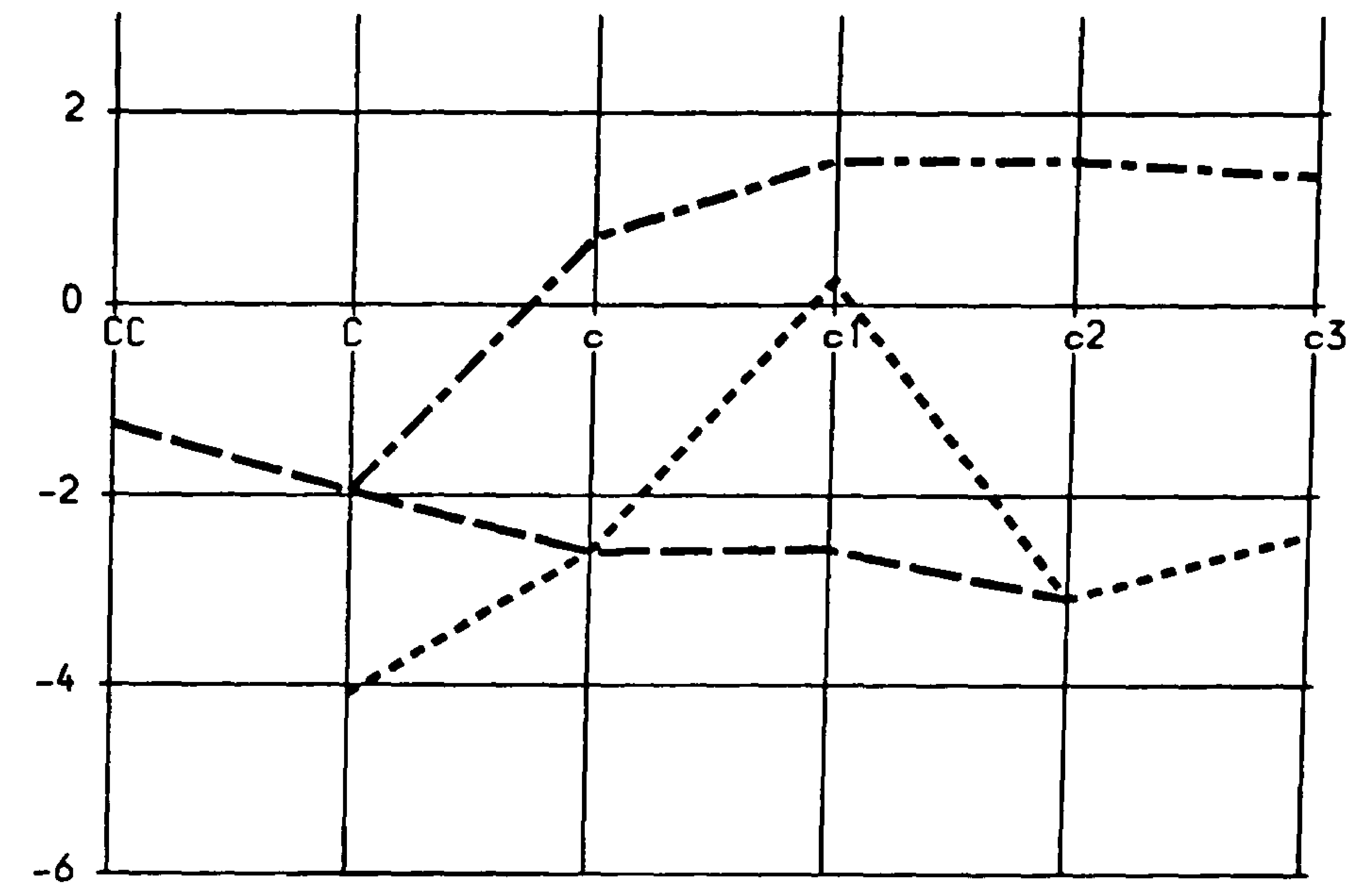
'many of them are adapted from standard and even special scales which consideration showed to be eminently suitable for a given situation.'[132]

The scales of French, German, Dutch and English builders were adapted and this reflects the outlook of the tonal design. Such a heterogeneous collection of unrelated sounds and colours created a hitherto unknown breed of organ, the so-called eclectic organ. This has now been



ROYAL FESTIVAL HALL (GREAT)

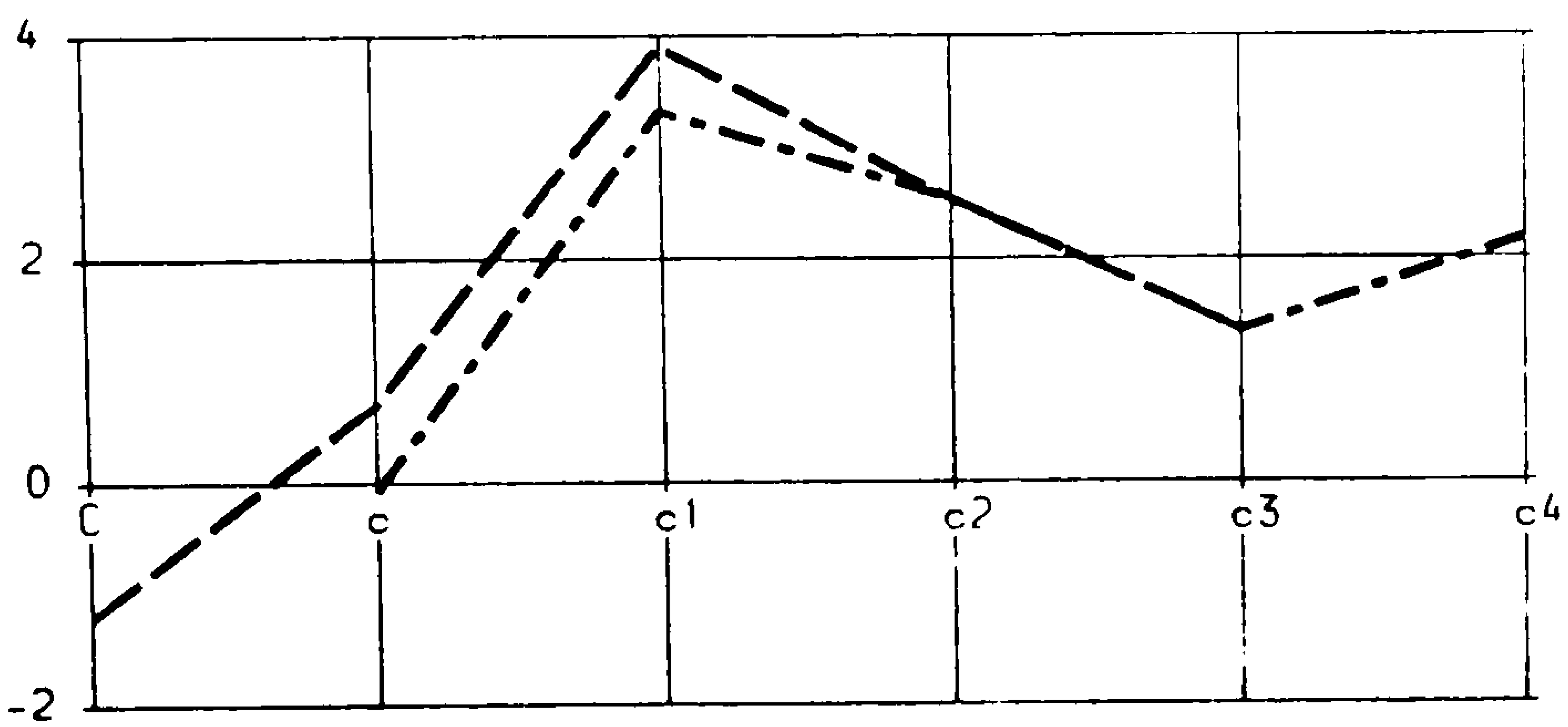
- Superoctave 2′
- Octave II 4′
- Octave I 4′



ROYAL FESTIVAL HALL (GREAT)

- Principal 8′
- Diapason 8′
- Principal 16′

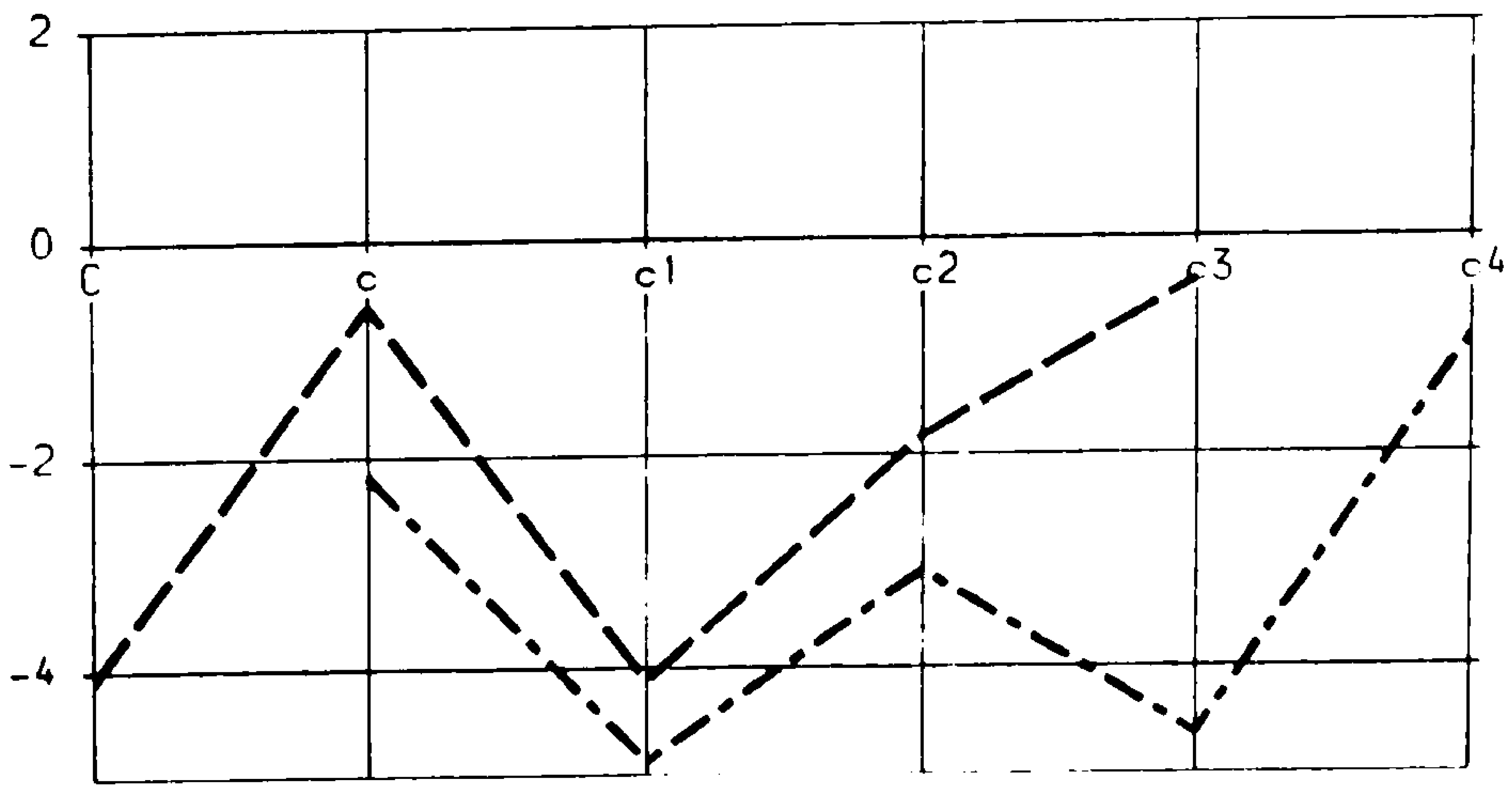
Figs. 30 (left) & 31 (right)



ROYAL FESTIVAL HALL (SOLO)

Octave 4′

Diapason 8′

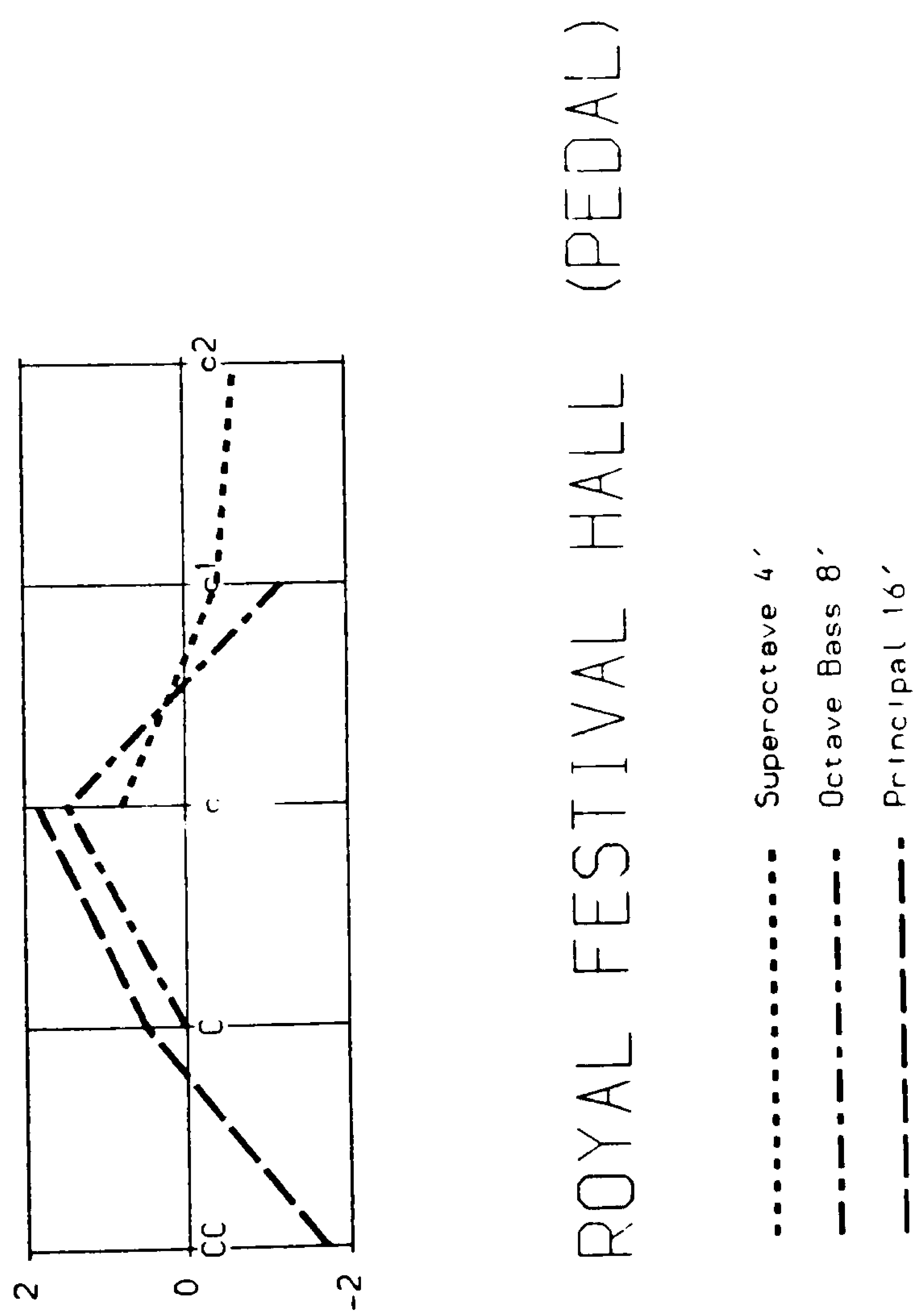


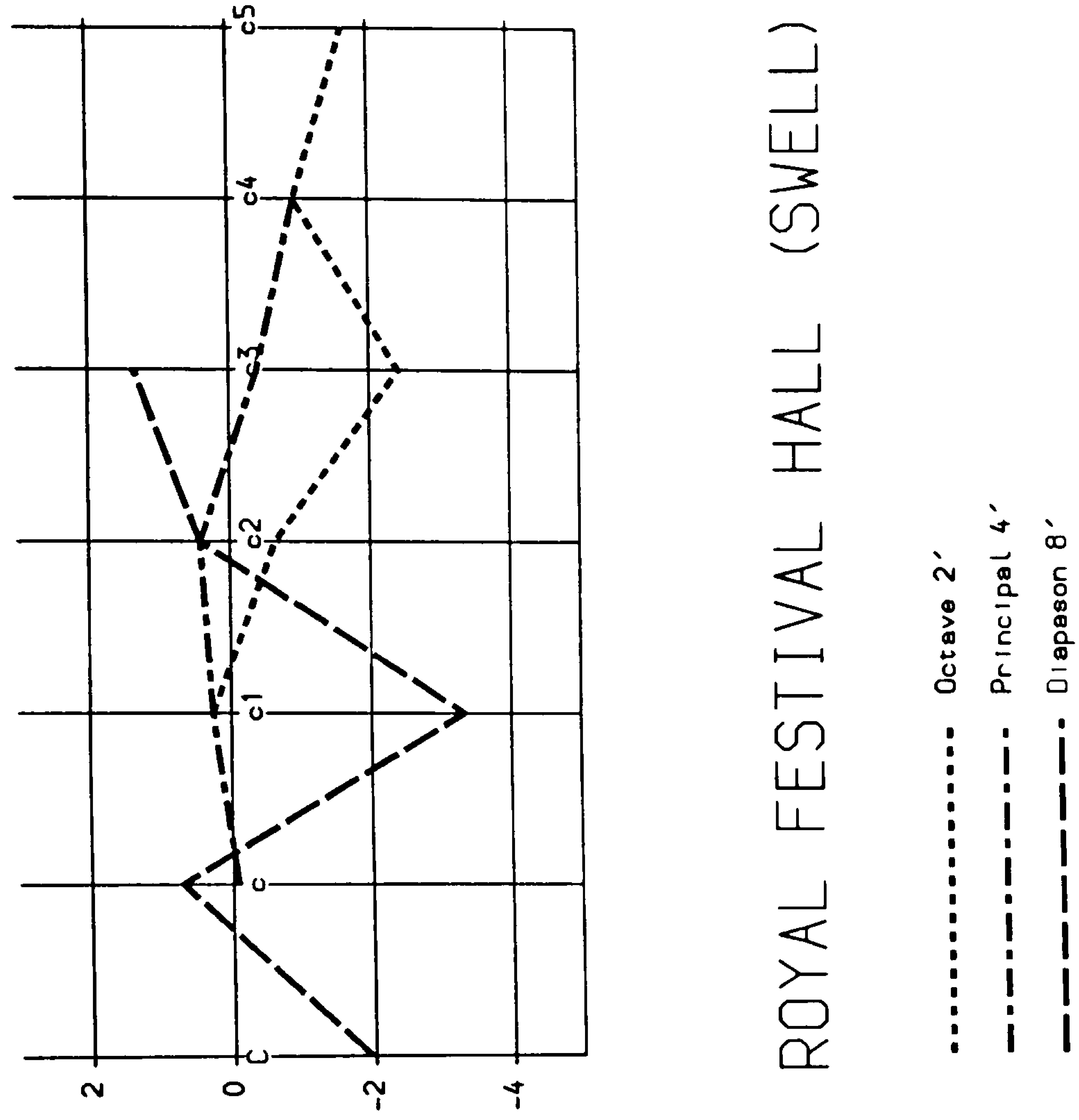
ROYAL FESTIVAL HALL (POSITIVE)

Octave 4′

Principal 8′

Figs. 32 (left) & 33 (right)





Figs. 34 (left) & 35 (right)

identified as being a worthless aim in organ-building, although this does not preclude the design of versatile instruments. From the point of view of coherent scale-design, such a philosophy makes no sense.

The pipe-scales for the Royal Festival Hall organ underwent considerable modifications (as did the specification) in the years leading up to its installation. Downes apparently showed the proposed scalings of the organ to Dirk Flentrop in 1949. Downes writes of this,

> '...he agreed to look at my scale-scheme: his comment on this was that too many of the scales "went the same way", ie, followed the same progression.'[133]

The scales at that time were constant Toepfer scales, halving on the seventeenth, eighteenth or nineteenth-pipes along with a few scales by Dom Bédos. The change from 'traditional' English scaling practice to the variable variety met with consderable opposition form the entrenched establishment. Downes writes

> 'Of course there were English organ-builders who pooh-poohed the whole idea of variable scales: "unscientific" - or even more caustically, "due only to crude methods of pipe-making, and therefore accidental".'[134]

The scales for the principal stops are given in the table below. The figure above any two c diameters represents the step on which the half-measure would fall over a one-octave interval. These scales are plotted at figures 30 to 35.

THE ROYAL FESTIVAL HALL ORGAN

Great Organ

	15.1	15.2	16.1	15.3	
Principal 16'	247.7	142.9	82.6	49.2	28.6

Diapason 8′	142.9	20.5	95.3	17.2	58.7	16.0	34.9	15.8	20.6
Principal 8′	130.2	18.3	82.6	21.0	55.6	12.5	28.6	16.9	17.5
Octave I 4′	87.3	18.5	55.7	13.6	30.2	15.2	17.5	25.9	12.7
Octave II 4′	87.3	18.5	55.7	16.7	33.3	17.3	20.6	22.8	14.3
Quint 2, 2/3′	65.1	21.9	44.5	13.3	23.8	16.3	14.3	20.3	9.5
Super Octave 2′	49.2	17.0	30.2	15.2	17.5	18.3	11.1	24.5	7.9

Swell Organ

Diapason 8′	142.9	20.5	95.3	12.0	47.6	23.3	33.3	17.3	20.6
Principal 4′	92.1	16.5	55.6	16.2	33.3	15.0	19.1	15.3	11.1
Octave 2′	55.6	14.9	31.8	13.9	17.5	11.3	11.1	15.1	6.4

Positive Organ

Principal 8′	130.2	22.5	90.0	12.4	46.0	19.8	30.2	18.2	19.1
Octave 4′	84.1	13.1	44.5	18.8	28.6	14.2	15.9	23.2	11.1

Solo Organ

Diapason 8′	147.6	19.0	95.2	21.9	65.1	14.4	36.5	14.5	20.6
Octave 4′	92.1	22.4	63.5	15.0	36.5	14.5	20.6	17.2	12.7

Pedal Organ

Principal 16′	242.9	19.6	158.8	18.0	100.0
Octave Bass 8′	155.5	18.2	98.4	13.1	52.2

Super Octave 4′ 95.6 14.6 54.0 15.7 31.8

Wind-pressures (im mm of wind)

Great Organ 92.6mm
Swell Organ 92.6mm
Positive Organ 70.5mm
Solo Organ 115.4mm
Pedal Organ 102.6mm

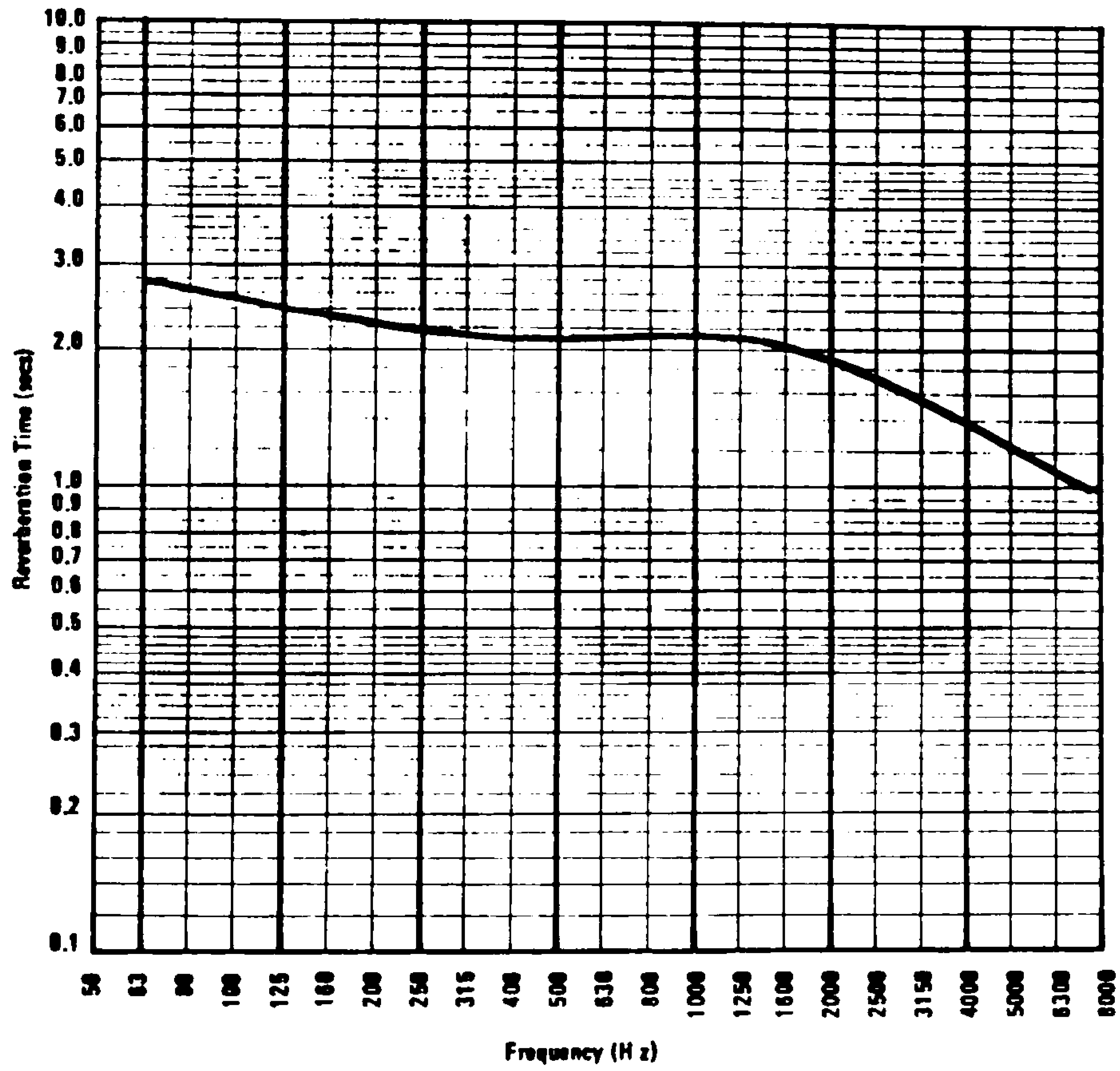
Certain scales (the Great Principal 16′. Diapason 8′ and many pedal stops) have the hall-marks of the Toepfer scales with little or no variability. Despite this, this organ represents the first English attempt to solve the question of scales, although it was still many years before the full combination of the many aspects of classical design were realised in this country. With the publication of the German, English and French journal of the International Society of Organ-Builders (<u>ISO Information</u>) in 1970 and <u>The Organbuilder</u> (1983) in this country. (both specifically for the organ-building trade), much more openness has been exhibited in the publication of individual organ-builder's scaling-practices. The secrecy which once surrounded pipe-scales has been exploded. This secrecy was founded upon a reliance on the convenient theories of Toepfer which in turn (for a short time) destroyed the inquisitive and researching nature of an organ-builder's craft, the kind of inquisitiveness that produced from men like Dom Bédos comprehensive treatises on the organ. The reliance upon such theories led to a situation where few organ-builders knew on what their scaling-practices were based.

With the new organ at St. David's Hall, Cardiff (Peter Collins, 1982) there came the opportunity to go through the creative process of organ design with the Royal Festival Hall experience in mind. Ralph Downes was appointed as tonal consultant by Cardiff City Council and South Glamorgan County Council. Collins wrote

> 'At an early stage the environment, scales and sound of the Royal Festival Hall organ were observed and discussed; although the disposition of the seating at Cardiff was different from the Royal Festival Hall (being similar to the Turner Simms Concert Hall, Southampton, where we had installed a 3-manual organ in 1977), nevertheless, the absorption of sound by an audience of this size was envisaged as a major factor in determining the scales. The audience at Cardiff sits in steeply raked terraces which expose approximately 20% more clothed torso than is normal, and this times a factor of 2000 (the number of people the Hall can hold) has a significant influence upon the power required from the instrument when the Hall is full. After assessing all the factors, we eventually decided upon a scale for the Great Principal 8, Octave 4, and Rauschquint 2 2/3 + 2, at mid-c, and these pipes were then carefully made and voiced on a pressure of 91mm w.g. These 'models' were taken to the Royal Festival Hall where they were made to sound on a small test machine and some minor adjustments to the output were made. After taking into account once again all the acoustical properties relating to 'our' Hall, it was then decided that the ouput level should be identical to that of the Royal Festival Hall Great Principal 8.'[135]

The acousticians provided a graph for proposed reverberation times, which in inverse form shows where the output-level from the pipes ought to be increased where the reverberation in the building is at its minimum and the absorption is at its maximum, (see fig. 36). In this way a pipe-scale may be adjusted to secure the optimum level of sound required from each pipe.

The Great Principal 8' at St. David's Hall is of



St. David's Hall, Cardiff - proposed reverberation times

Fig. 36

substantial scale and (as has become a more commonly accepted practice, although far from being universally accepted, particularly in this country) has variable cut-up and mouth-width/circumference ratios.

St. David's Hall, Cardiff (Peter Collins, 1982)

Great Organ

Principal 8'	C		c		c1		c2		c3		a3
		18.1		13.7		15.4		18.1		25.9	
Diameter	153.0		96.5		52.6		30.6		19.3		14.0
Mouth-width 1 as proportion	4.0		4.0		4.0		3.9		3.8		3.7
Mouth-width 2 actual size	121.0		76.5		41.5		24.5		16.0		11.8
Cut-up	35.0		22.0		12.2		7.0		4.3		3.1
Octave 4											
		15.4		18.2		15.9		17.5		28.9	
Diameter	88.5		51.5		32.6		19.3		12.0		9.0
Mouth-width 1 as proportion	4.0		3.8		4.0		3.9		3.8		3.8
Mouth-width 2 actual size	70.0		42.7		25.8		15.6		9.9		7.4
Cut-up	21.0		12.0		7.3		4.3		2.5		1.7
Rauschquint 2 2/3											
		19.2		14.6		16.7		17.1		22.7	
Diameter	64.0		41.5		23.5		14.3		8.8		6.1
Mouth-width 1 as proportion	4.2		4.5		4.2		4.0		4.0		3.9
Mouth-width 2 actual size	48.0		29.0		17.7		11.3		7.0		4.9
Cut-up	14.2		8.0		4.8		3.1		1.5		1.3
Rauschquint 2											
		15.3		17.4		19.3		16.2		28.9	
Diameter	50.5		29.0		18.0		11.7		7.0		5.25
Mouth-width 1 as proportion	4.0		4.0		4.0		3.9		3.8		3.7
Mouth-width 2 actual size	40.0		23.0		14.2		9.5		5.8		4.4
Cut-up	12.3		6.5		3.8		2.6		1.2		1.0

Swell Organ

Principal 8											
		16.9		15.4		20.2		16.7		21.3	
Diameter	145.0		88.5		51.5		34.1		20.7		14.0

Mouth-width 1 as proportion	4.0	3.9	3.7	4.0	4.0	4.0
Mouth-width 2 actual size	115.0	71.5	43.0	27.0	16.4	11.0
Cut-up	36.4	18.3	10.0	6.5	3.9	2.8

Octave 4

		18.8	15.7	14.7	14.1	21.0
Diameter	90.0	57.8	34.0	19.3	10.7	7.2
Mouth-width 1 as proportion	4.0	4.1	4.0	3.8	3.6	3.5
Mouth-width 2 actual size	71.0	44.0	27.0	16.0	9.3	6.5
Cut-up	21.0	11.0	6.4	4.4	2.3	1.6

Positive Organ

Principal 4

		15.8	14.4	15.2	17.2	37.3
Diameter	84.7	50.0	28.0	16.2	10.0	8.0
Mouth-width 1 as proportion	4.0	4.0	3.9	3.8	3.7	3.7
Mouth-width 2 actual size	67.0	39.5	22.5	13.4	8.5	6.8
Cut-up	18.0	10.5	6.7	3.8	2.0	1.5

Octave 2

		14.7	18.5	15.9	18.1	22.6
Diameter	48.0	27.3	17.4	10.3	6.5	4.5
Mouth-width 1 as proportion	4.0	4.0	4.0	3.8	3.7	3.6
Mouth-width 2 actual size	38.0	21.6	13.8	8.5	5.5	3.9
Cut-up	11.0	6.4	3.3	2.0	1.1	0.8

Pedal Organ

Principal 16	C	c	c1	g1
		15.5	19.2	29.1
Diameter	255.0	149.0	96.5	72.5
Mouth-width 1 as proportion	4.0	4.0	4.0	4.0
Mouth-width 2 actual size	202.0	118.0	76.5	57.5
Cut-up	62.0	41.0	21.0	15.0

Octave 8

		16.7	14.8	24.2
Diameter	159.0	96.5	55.0	39.0
Mouth-width 1 as proportion	3.8	3.9	4.0	4.0
Mouth-width 2 actual size	132.0	78.0	43.5	31.0

Cut-up	37.0	21.5	12.0	8.0

These figures for Collins' cut-up and mouth-width/circumference ratios for the C pipes were 'arrived at empirically simply by listening'.[136] These figures were then used to interpolate the intervening semitone steps using the Rensch slide-rule. The Great Principal chorus scalings (Principal 8, Octave 4, and Rauschquint 2 2/3 + 2) taken as a whole, cover a wider band of sound at tenor c than at the other points in the compass. This was done

> 'so that this combination gives a very full tenor line, but not a dominant one - a very useful component for fugues.'[137]

Many of the scales display Schnitger-type features in the widening of the scales in the last octave, a process even extended to the pedal division.

Peter Collins probably represents the most forward looking organ-builder in this country at the present time. Collins worked for Rieger in Austria in 1964, for it is on the European Continent (and now to some extent in the United States of America) that a keen awareness of the benefits of intimately worked scales has been evident for some time. Scaling by other British builders indicated that the Toepfer *Normalmensur* is far from being by-passed and constant scales are still very much the order of the day. the fixed-variable and free-variable varieties being a virtually untouched field in this country. This is hardly surprising when many British firms have yet to make their first revival mechanical organ (e.g. Henry Willis 4). Partly to blame is the highly contagious disease of copying old scales. Whilst study of such scales is important and application of them quite legitimate and appropriate in an acoustic environment which is similar to the location of the organ from which the scales are copied, such copying is a futile exercise when the resulting organ lacks clarity because the scales and resulting tonal outlook of the organ are unsuited to the new acoustic environment.

The use of the Rensch slide-rule can only be construed a good thing for organ-builders, as it encourages experimentaion and deepens the understanding as to what kind of scale might be appropriate for a particular job. Unfortunately, the Rensch system only allows logarithmic scaling and deviations from these scales (such is the legacy of the German theorists) and Bédos-type scales are quite impossible to design on that system other than by drawing the scales free-hand and then interpreting then from drawings by using the Rensch System. The resurgence of interest in Dom Bédos subsequent to the *reform of the reform* has been aptly summarised by Joseph von Glatter-Goetz (the head of the Rieger firm) as follows:

> 'The schools threw their 8+8+8+4-practice and teaching organs out and ordered 8+4+2+1-ones to properly play Buxtehude and Bach. When they had them they wanted to play Rheinberger and Reger on them. When this did not work either, all peeped over the fence into France: what mellow sound, like its cheese and wine, yet forceful and spicy like steak-au-poivre and calvados! What continuency in composition and performance like the annual harvest of its pastures and vineyards!
>
> Dom Bédos was translated into German and so was the French organ. And wasn't Albert Schweitzer, the Father of all reform and movement, as French as he was German?'[138]

CHAPTER THREE

THE CALCULATION OF PIPE-SCALES

End-Correction

In 1878, R.H.M. Bosanquet published a paper[1] dealing with the relationship between the notes of open and stopped pipes in which he wrote:

> 'GENTLEMEN,
> It has long been known to practical men that, if an open pipe be stopped at one end, the note of the open pipe, as it is not exactly the octave below the note of the open pipe, as it should be according to Bernouilli's theory,[2] but the stopped pipe is somewhat less than an octave below the open pipe; in ordinary organ-pipes the difference is said to be about a major seventh instead of an octave.'[3]

Bosanquet went on to consider a cylindrical tube, open at both ends, of length l and diameter 2R. The effective length of the tube is given below as

$$l + 2\alpha \qquad 3.0$$

where α is the correction for one open end.

On placing a flat stopper to the top of the pipe, the stopper coincides with the nodal-point. The length of the corresponding open pipe would be

$$2(l + \alpha) \qquad 3.1$$

where $l + \alpha$ is the effective length measured from the node.

The ratio of the notes generated in the open and stopped pipes is then

$$(l + 2\alpha) : 2(l + \alpha) \qquad 3.2$$

which is equivalent to

$$\frac{1}{2} \times \frac{l + 2\alpha}{l + \alpha} \qquad 3.3$$

Bosanquet calculates the approximate value of α by estimating the ratio between the pipes aurally as 9/8. Thus, from 3.3

$$\frac{9}{8} = \frac{1 + 2\alpha}{1 + \alpha} \qquad 3.4$$

or

$$\frac{1}{8} = \frac{\alpha}{1 + \alpha} \qquad 3.5$$

therefore,

$$1 = 7\alpha$$

$$\underline{\alpha = 0.7R}$$

where l= 4.9 inches
and R= 1 inch

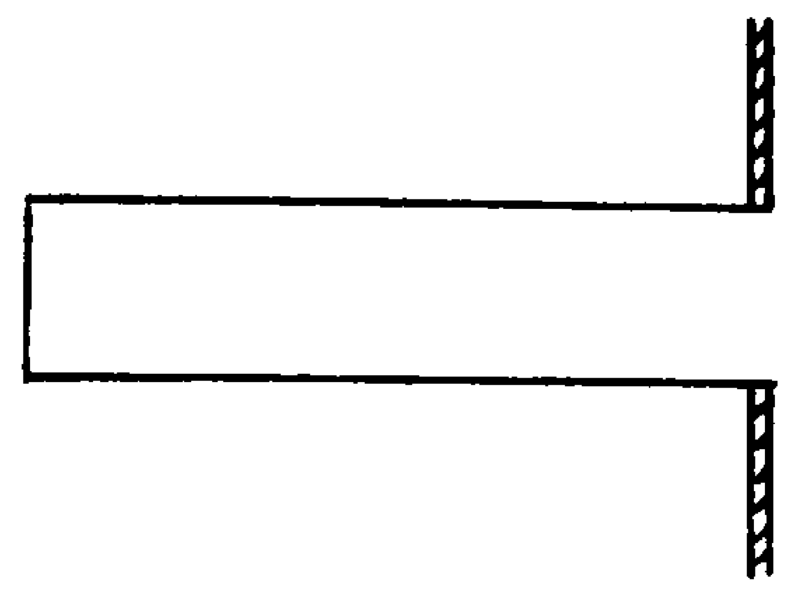
In Bosanquet's method, the pitches of the open and stopped pipes were compared with an 'enharmonic organ', and thus not measured accurately. Lord Rayleigh[4] made an approximate calculation of the end correction for the open end of a pipe, assuming that the open end was fitted with an infinite flange.

Rayleigh wrote in 1877[5]

> 'Experimental determinations of the correction of an open end have generally been made without the use of a flange, and it therefore becomes important to form at any rate a rough estimate of its effect. No theoretical solution of the problem of an unflanged open end has hitherto been given, but it is easy to see (§§ 79, 307) that the removal of the flange will reduce the correction materially below the value .82R.[6] In the absence of theory, I have attempted to determine the influence of the flange experimentally. Two organ-pipes nearly enough in unison with one another to give comfortable beats were blown from organ bellows; the effect of the flange was deduced from the difference in the frequencies of the

> beats according as one of the pipes was flanged or not. The correction due to the flange was about 0.2R. A (probably more trustworthy) repetition of this experiment by Mr Bosanquet gave 0.25R. If we subtract 0.22R from 0.82R we obtain 0.6R which may be regarded as about the probable value of the correction for an unflanged open end, on the supposition that the wave length is great in comparison with the diameter of the pipe.'[7]

Frobenius and Ingerslev[8] computed the end-correction under the assumption that the open end of a stopped column is placed in a baffle of infinite extent.



A stopped column placed in a baffle of infinite extent Fig. 37

A.E. Bate stated in 1930,[9] that the end-correction at the open end is independent of the frequency of the pipe, and gives the correction as 0.66R. On removal of the baffle, the end-correction is slightly altered. Frobenius and Ingerslev's calculation with the baffle gives the open end as being approximately 0.85R. Thus the removal of the baffle alters the end-correction to the order of 0.16R which is closer to Rayleigh's 0.2R than Bosanquet's 0.25R.

Despite the fact that Anderson and Ostensen[10] showed in 1928 that end-correction is dependent upon frequency, Bate in 1930 stated that the end-correction was independent of frequency. It is now generally accepted that whilst frequency is a factor, although

> 'the variation is too small to be of any practical significance.'[11]

Anderson and Ostensen used Blaikley's[12] experimental method for determining end_correction at the open end: the pipe being mounted vertically with the open end at the top and the length of the vibrating column altered by letting water in or out at the bottom. A glass gauge tube 3.3 cm inside diameter being set parallel to the pipe and connected at the bottom to the same water intake. A tuning fork, electronically driven, was mounted 7-10 cm above the open end of the pipe. The height of the fork above the open end if less than 7 cm had no effect on the end-correction.

The method consists of finding the shortest resonant length (l') of a closed pipe when forced to vibrate by the action of a tuning fork, and the next longer resonant length (l''). The correction is given by

$$\frac{(l'' - l')}{2 - l'} \qquad 3.6$$

The experiments were carried out using three pipes of diameters 992 mm, 736mm, and 484mm. Anderson and Ostensen showed that for each pipe, the correction underwent an increase, followed by a decrease. The decrease was greatest with the largest pipe and becomes smaller with a decrease in the diameter of the pipe. Small changes in the magnitude of the end-correction occur as the wavelength is raised.

The table below shows the end-corrections for unflanged cylindrical pipes as calculated by various investigators. (R is the radius in a circular cross-section). Levine and Schwinger's calculation is now accepted as being the most accurate.

AUTHOR(S)	END CORRECTION
Lord Rayleigh	0.6R
R.H.M. Bosanquet	0.635R / 0.7R
D.J. Blaikley	0.576R
W.M. Boehm	0.656R
A.E. Bate	0.66R
H. Levine and J. Schwinger	0.6133R

The end-correction at the mouth of the pipe is much more difficult to calculate. Rayleigh[13] showed that the end-correction can be calculated if the opening is elliptical rather than circular, and that the end-correction of a circular opening of the same area as an elliptic opening is equal to that of an elliptic opening when multiplied by a factor[14]

$$K(e)=\frac{2}{\pi} \; F(e) \; \sqrt[4]{1 - e^2} \qquad 3.7$$

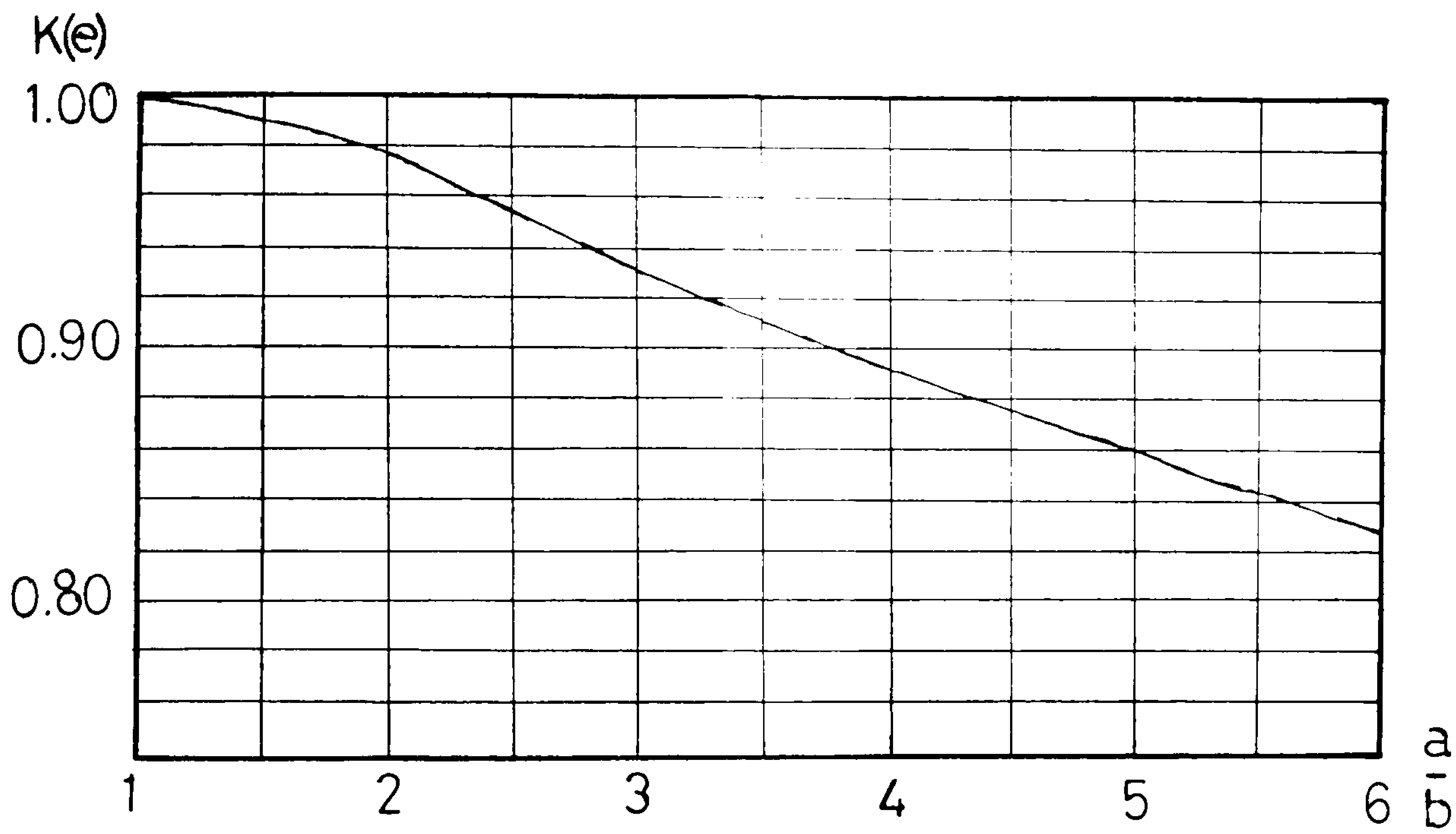
where e is the eccentricity of the ellipse.
F(e) is the symbol of the complete elliptic function of the first order.

The practical solution to this equation is given in full in appendix B.

Ingerslev and Nielsen[15] have shown that a rectangular opening (the mouth of the pipe) acts in the same way as an elliptic opening. The eccentricity of the ellipse (e) is given as

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2} \qquad 3.8$$

where a and b are the axes of the ellipse. The graph at figure 38 plots K(e) as a function of the ratio of a/b



$$K(e) = \frac{2}{\pi} F(e) \sqrt[4]{1 - e^2}$$

Fig. 38

between the axes of the ellipse.

Practically, for organ-builders, the ratio of mouth-width to height is commonly 4:1, so, when a/b=4, K(e)=0.89. Frobenius and Ingerslev[16] give the formula for end-correction at the mouth of the pipe as

$$\cot kl = 1.30r \; \frac{R^2}{ba} \; \frac{K(e)}{0.89} \; k \qquad 3.9$$

where
k = wave number ($2\pi f/c$)
l = length of the tube
r = radius in a circular opening of the same area as the mouth of the pipe

$$r = \sqrt{\frac{\frac{b}{a}}{\pi}}$$

R = radius of the pipe's cross-section
1.30 = the coefficient for the consumption of air

The derivation of this formula is given in appendix B.

Tests for the calculation of pipe-length

To test the formula rigorously, an experiment was set up as shown in figure 39. An electrical motor (a) supplied wind held under pressure using a concussion valve (b) as bellows. The pressure was measured using an anemometer as being 75mm of water. The wind from the bellows was delivered to a small sound board (c) holding ten pipes. The pipes spoke via the depression of a finger pad (d), (the 'key'), which was directly connected to the pallet below.

Eight open diapason pipes were used, seven of which were made of 'spotted' metal (approx. 60% tin, 40% lead) and one of 'plain' metal (approx. 10% tin, 90% lead). Two

TEST ORGAN

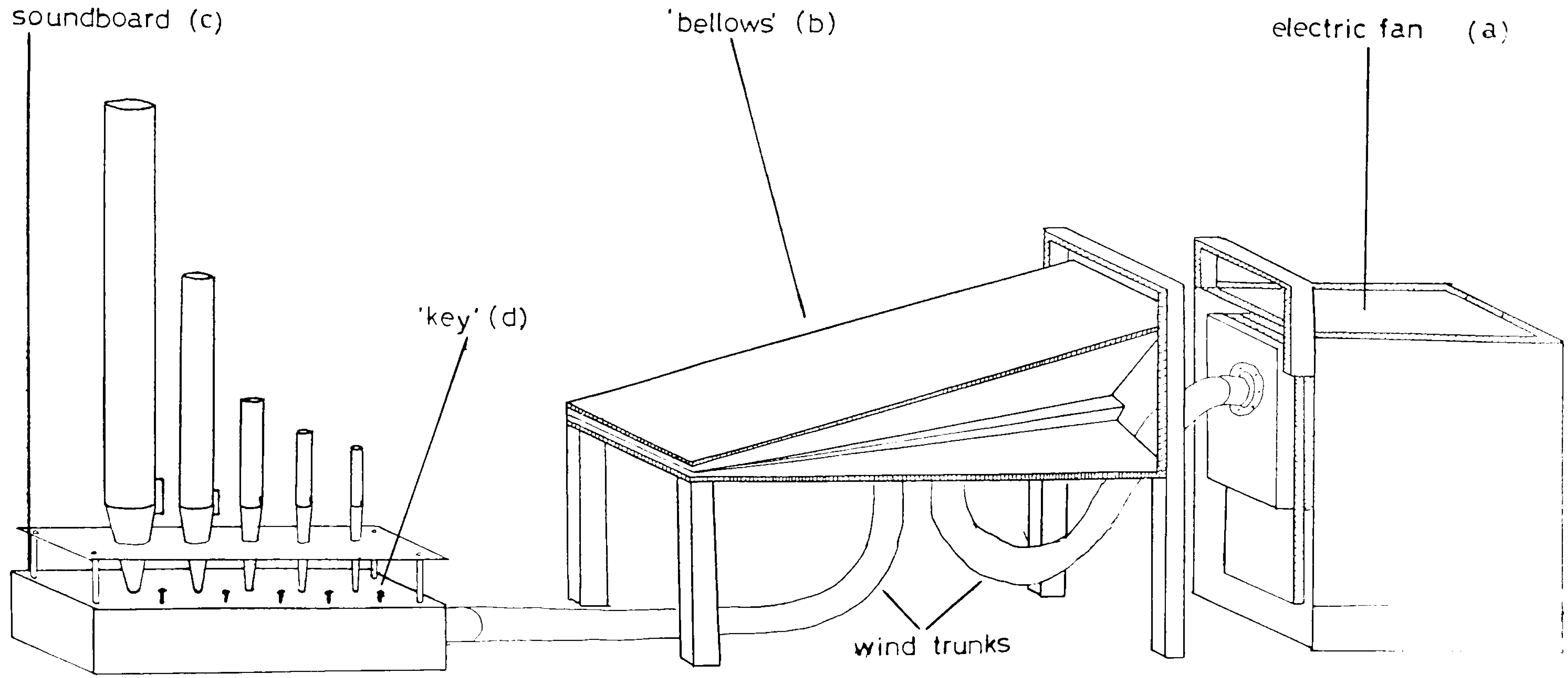


Fig. 39

other pipes were used: a blockflute and a salicional, representing wide-and narrow-scales, to examine how the results varied with extremes of scale.

The pipe-dimensions were carefully measured and the diameters measured in two ways:

(i) directly, in so far as this was possible using a pair of dividers, and

(ii) by $r = \frac{\text{circum}}{2\pi}$, d=2r , for which the thickness of the metal was subtracted, as the outside circumference was measured.

The temperature was recorded at 18.8°C using a mercury thermometer. The pipes were left at room temperature and their lengths measured with a minimum of handling . All tuning-slides were removed so that both the length of the pipe could be accurately determined and so as to avoid the possibility of tuning slides slipping. The frequency of each pipe was measured using a digital frequency counter and the details noted in the table below. The results of the calculations are given below, and appear in full in appendix C.

All pipes, with the exception of open diapason number 4 were made of 'spotted' metal. Diapasons 1,2,3, the Salicional and Blockflute had ears, whilst diapasons 4 to 8 had none. The results do not indicate that the absence or presence of ears has any effect on the calculation of pipe-length in this context. The wind-pressure was recorded at 75mm of wind for all pipes. The results are tabulated in figure 40.

Test organ pipe-calculations: results

Pipe Type	Freq. (Hz)	Circ-umf.	Diam. calc'd	Diam. measured	Mouth width	Mouth height	Metal thi'nss	Physical length	Calculated length measured	Calculated length calc'd	Mouth ratio	Mouth/Circ. ratio	Effective length	Error Measured	Error Calc'd
Diap1	262.0	166.0	51.24	53.0	38.0	11.0	0.8	570.8	566.82	571.66	3.5	4.4	653.74	-4.0	+0.9
Diap2	527.9	96.0	28.96	28.5	21.0	6.0	0.8	276.0	278.45	277.21	3.5	4.3	324.45	+2.5	+1.2
Diap3	785.8	75.0	22.47	23.0	17.5	5.0	0.7	180.0	182.22	183.55	3.5	4.1	217.97	+2.2	+3.6
Diap4	818.1	71.0	20.66	21.0	15.0	4.8	1.0	176.0	177.69	178.68	3.1	4.4	209.36	+1.7	+2.7
Diap5	1058.5	65.0	19.49	19.0	14.0	4.0	0.6	131.5	131.88	130.66	3.5	4.3	161.77	+0.4	-0.8
Diap6	1314.1	56.0	16.63	17.0	13.0	3.9	0.6	105.5	105.42	106.27	3.3	4.1	130.34	-0.1	-0.8
Diap7	1596.6	51.0	14.83	14.8	11.2	3.3	0.7	85.4	85.32	85.25	3.4	4.2	107.28	-0.1	-0.2
Diap8	2131.2	42.0	11.77	10.9	9.0	2.2	0.8	60.0	63.02	60.95	4.1	3.8	80.37	+3.0	+0.9
Block-flute	260.7	208.0	64.61	65.3	39.5	12.3	0.8	532.0	543.75	545.69	3.2	5.1	656.99	+11.8	+13.7
Salic-ional	265.0	102.0	30.67	30.3	21.2	7.0	0.9	562.0	599.55	598.54	3.0	4.6	646.34	+37.6	+36.5

Fig. 40

The results show clearly that the errors are well within acceptable limits for the cutting of sheet metal to the required length in the factory shop. The calculations are not as accurate for the Blockflute and less so for the Salicional pipe. The pipes of the Blockflute stop are characterised by a very wide diameter for its frequency and a very small mouth-width for the large diameter. The Salicional has a different problem. Here the results were quite inaccurate. The Salicional is traditionally a slotted pipe, the size and position of the slot cut in the pipe being at the discretion of the organ-builder. The speaking length of the pipe is only to the base of the slot, of the position of the tuning slide. The total speaking length to the base of the slot in this case was 563mm (none of the pipes used in the experiment retained their tuning slides). The total length of the pipe was 629mm. The reason for the errors in calculating the lengths of these two pipes lies in the fact that the pipes are of extreme scale in comparison to their frequency. Neither of these pipe-types are easy to voice and it could be argued that they are forced by the voicer to speak notes that they might not otherwise have done 'naturally'. The investigation into the exact sources of these errors is not pursued in this thesis, as the main concern here is the calculation of pipe-length for open diapason or principal pipes.

In order to test the formula rigorously and to ensure that it was accurate for pipes both larger and smaller than those used on the test organ, a second experiment was conducted. This was not done under the controlled conditions of the first experiment for reasons that will become obvious. The second test involved measuring a rank of pipes *in situ*. These pipes are on the pedal division of the organ in the Chapel of the College of St. Hild and St. Bede, Durham. In order to avoid small changes in pipe-length, the pipes were not handled during measurement. The pipes were measured as they stood on the soundboard the temperature being 11° C and the organ tuned in equal temperament to A440 Hz. The results of this second test are given below along with the measurements of the pipes. The pipes in question were case pipes made by George Summerscale of Harrison and Harrison and came from the Great Organ of an instrument made by Harrison and Harrison for a church in Murton, County Durham. For symmetry of case disposition, the alternate tones from C# to d# are of the same diameter as those of the tones from C to d. These ex-case pipes have extra-long feet and were slotted (but not at present). The stepped bass register in fig. 41 clearly shows the duplication of diameters. The diameters, following a logarithmic scale, are plotted against the Toepfer *Normalmensur* (halving on step sixteen).

The table below shows the measurements taken from the pipe-work. The measurements given for the circumference of certain pipes were taken either for ease of measurement (bass pipes) or where some damage had occurred and exact measurement of the pipes proved difficult.

College of St. Hild & St. Bede, Durham University
(G. Summerscale)
Pedal Principal 8 , Fifteenth 4 , Twenty second 2
(Extension)

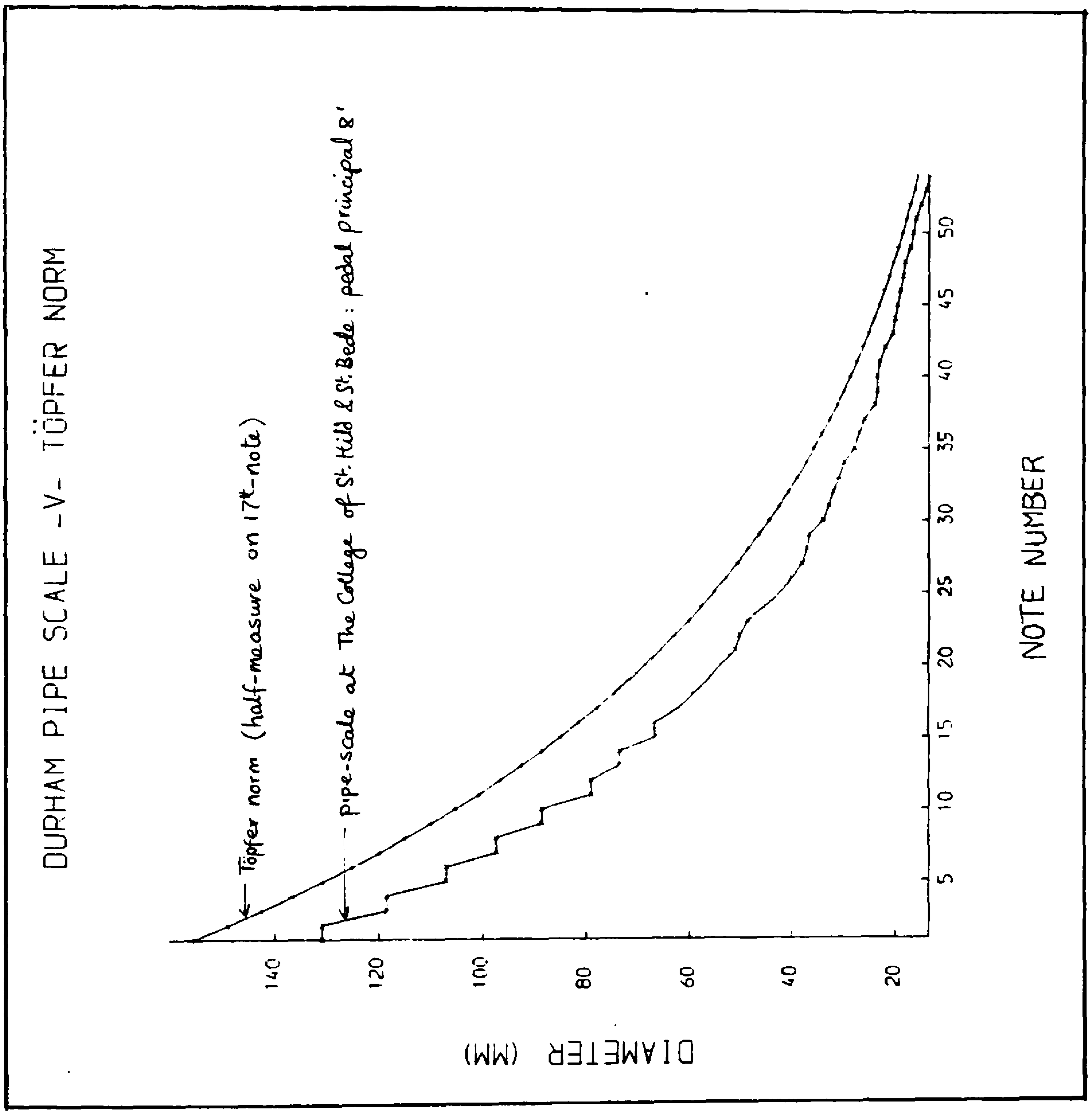

DURHAM PIPE SCALE -V- TÖPFER NORM
Töpfer norm (half-measure on 17th-note)
pipe-scale at The College of St. Hild & St. Bede : pedal principal 8'
DIAMETER (MM)
140
120
100
80
60
40
20
NOTE NUMBER
5
10
15
20
25
30
35
40
45
50

Fig. 41

Ex-Harrison & Harrison organ at Murton, Gt. Open Diapason

Note		Diameter	Length	Mouth Ht	Mouth Width	Mouth Ratio	Circum	Error (mm)
C	1	130.917	2379.0	28.5	98.5	3.456	416.0	- 6.4
C#	2	130.917	2243.0	28.5	98.5	3.456	416.0	-15.0
D	3	118.503	2113.0	26.0	88.0	3.385	377.0	- 1.0
D#	4	118.503	1998.0	26.0	88.0	3.384	377.0	-15.0
E	5	107.044	1886.0	23.0	79.5	3.456	341.0	- 9.5
F	6	107.044	1768.0	23.5	80.0	3.404	341.0	- 3.4
F#	7	97.439	1675.0	21.5	71.5	3.372	311.0	- 3.3
G	8	97.439	1569.0	22.0	71.0	3.227	311.0	+ 3.1
G#	9	88.582	1488.0	20.0	67.0	3.350	283.0	+ 1.0
A	10	88.582	1398.0	20.5	65.0	3.171	-	+ 2.4
A#	11	79.0	1324.0	18.0	60.0	3.333	-	+ 3.6
B	12	79.0	1242.0	17.5	59.0	3.371	-	+ 1.5
c	13	73.5	1178.0	17.0	57.0	3.353	-	+ 0.7
c#	14	73.5	1100.0	16.0	54.0	3.375	-	+ 1.4
d	15	66.5	1046.0	15.5	49.0	3.161	-	+ 0.5
d#	16	66.5	985.0	15.0	51.0	3.400	-	- 2.4
e	17	62.1	938.0	14.5	46.0	3.172	199.0	- 7.1
f	18	59.3	879.0	15.0	44.5	2.933	190.0	+ 3.7
f#	19	56.1	829.0	14.0	41.0	2.929	180.0	+ 3.1
g	20	53.9	781.0	13.5	38.0	2.815	173.0	+ 3.1
g#	21	50.9	734.0	13.0	37.0	2.846	164.0	+ 2.2
a	22	50.0	696.0	12.5	36.0	2.880	-	- 0.2
a#	23	48.5	655.0	12.0	34.0	2.833	-	- 0.7
b	24	45.0	617.0	11.5	33.0	2.870	-	+ 3.3
c1	25	42.0	584.0	11.0	31.0	2.818	-	+ 3.2
c#1	26	40.0	558.0	10.5	28.0	2.667	-	- 4.5
d1	27	38.0	519.0	10.0	27.5	2.750	-	+ 3.4
d#1	28	37.0	489.0	10.0	26.0	2.600	-	+ 3.3
e1	29	36.5	463.0	10.0	26.0	2.600	-	+ 0.1
f1	30	34.0	437.0	9.5	26.0	2.737	-	+ 1.6
f#1	31	33.0	411.0	9.0	24.0	2.667	-	+ 0.9
g1	32	32.0	389.0	8.8	23.0	2.614	-	- 1.2
g#1	33	31.0	367.0	8.5	22.5	2.647	-	- 2.0
a1	34	30.0	344.0	8.0	21.5	2.688	-	- 1.3
a#1	35	28.0	325.0	8.0	19.0	2.375	-	+ 0.2
b1	36	27.0	304.0	7.5	19.0	2.533	-	+ 1.8
c2	37	26.0	292.5	7.0	18.5	2.642	-	- 5.1
c#2	38	24.0	273.0	6.5	18.0	2.769	-	- 0.8
d2	39	23.5	250.0	6.5	17.0	2.615	-	+ 6.2
d#2	40	23.5	242.0	6.5	16.5	2.538	-	- 2.0
e2	41	23.0	228.0	6.0	16.5	2.750	-	- 3.6
f2	42	22.0	214.0	6.0	15.5	2.583	-	- 1.8
f#2	43	20.5	200.0	5.2	15.0	2.727	-	+ 0.4
g2	44	20.0	190.0	5.0	14.5	2.900	-	- 3.0
g#2	45	19.5	177.5	4.8	14.0	2.917	-	- 2.1
a2	46	19.0	168.0	5.0	14.0	2.800	-	- 2.0
a#2	47	18.5	157.0	5.0	13.5	2.700	-	- 0.7
b2	48	18.0	148.0	5.0	13.0	2.600	-	- 0.7
c3	49	17.0	140.0	5.0	13.0	2.600	-	- 0.1
c#3	50	16.5	131.0	4.8	12.5	2.604	-	- 0.3
d3	51	16.0	124.0	4.8	12.5	2.604	-	- 0.1
d#3	52	15.0	115.0	4.5	11.5	2.856	-	+ 0.7
e3	53	14.0	108.0	4.0	11.0	2.750	-	+ 2.1
f3	54	13.5	101.0	4.0	10.5	2.625	-	+ 3.0

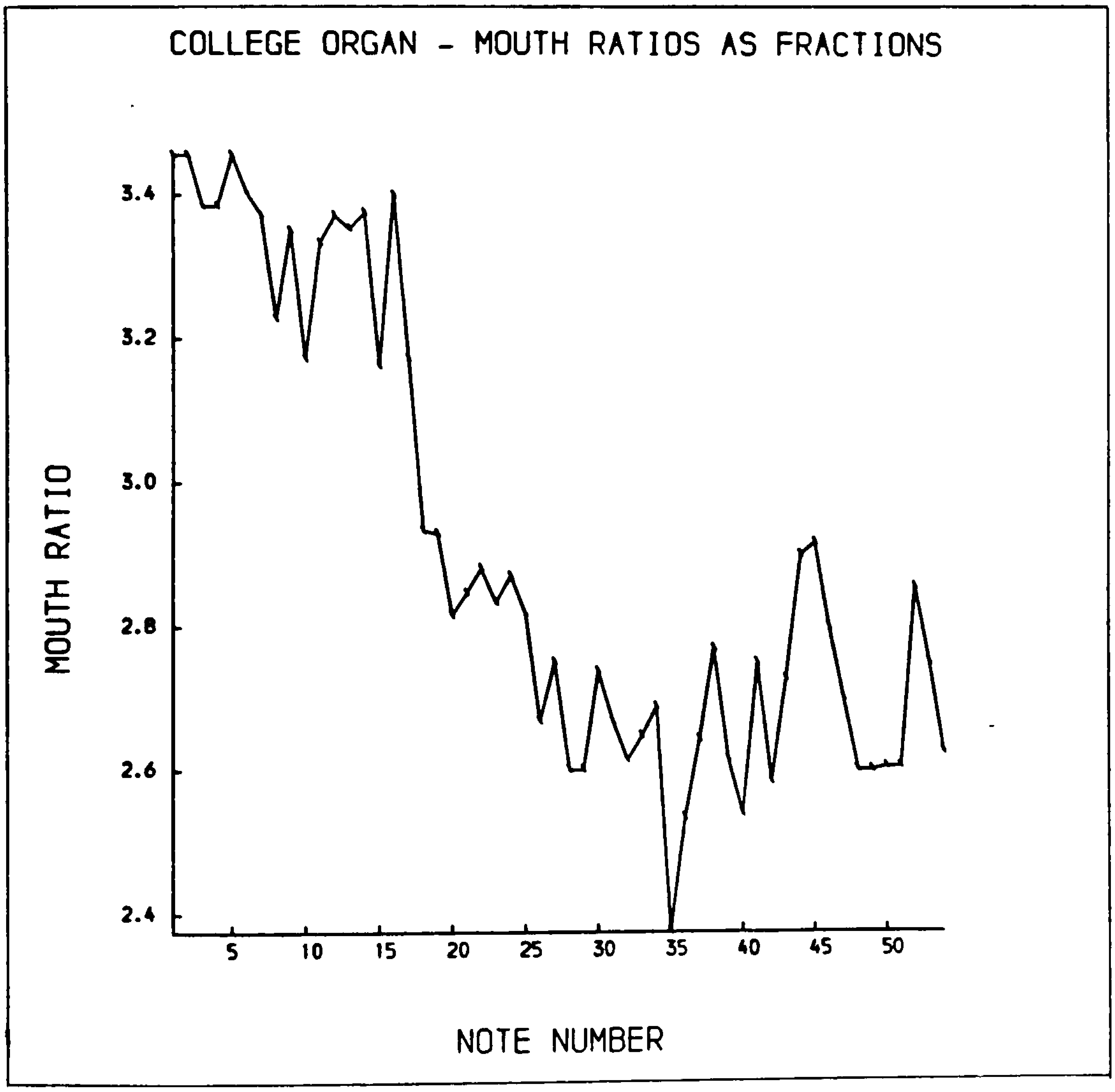
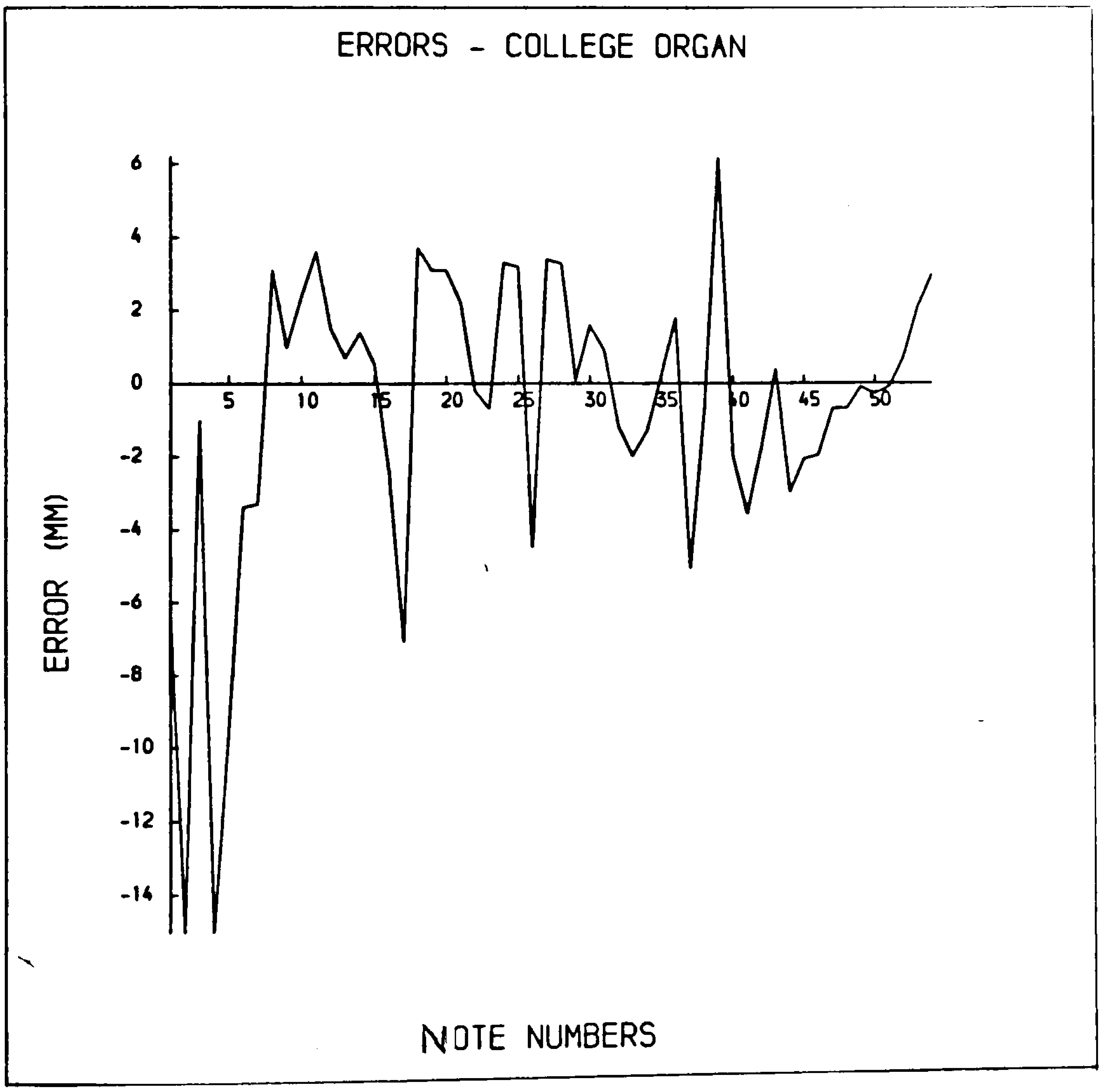

COLLEGE ORGAN - MOUTH RATIOS AS FRACTIONS
MOUTH RATIO
3.4
3.2
3.0
2.8
2.6
2.4
5
10
15
20
25
30
35
40
45
50
NOTE NUMBER

Fig. 42

One of the major problems in measuring pipes to a high degree of accuracy is that the older the pipes, the more damaged they are likely to be as a result of cone-tuning. One of the effects of this tuning method is to distort the diameters to the point that exact measurement is very difficult. There were several pipes in this series afflicted thus. Many pipes have been revoiced for their present incarnation and this is apparent in a comparison of mouth ratios, plotted below in fig. 42. The bass register from C1 - e17 have a 2/7th mouth (3.5) and the rest of the rank have approximately 2/5th mouths (2.5). Major deviation from these figures in the register coincide with obvious revoicings affecting the upper-lip. The full results of the calculations are given in the second part of appendix E.

The errors between calculation of pipe-length and physical pipe-lengths are plotted in figure 43. With the exception of C1, C#2, D#4, E5, e17, c'37 and d'39 the errors are within + or - 5mm of their physical lengths. These results contrast favourably with the results of the former experiment using the test organ, where the errors are no greater than 2.2mm deviation from the physical pipe length. To a great extent, the errors from the College Organ are expected, contrasting the more stringent conditions of the former test and pipe deformation allied to slight variations in the cut-up (in which case an average measurement was used) in the latter test. The effect of the leading edge of the languid and the lower-lip not being parallel and slight repositioning of the ears during the process of revoicing are not possible to ascertain at present. Although the



ERRORS - COLLEGE ORGAN
ERROR (MM)
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
5
10
15
20
25
30
35
40
45
50
NOTE NUMBERS

Fig. 43

effect of a variable cut-up has been discussed by Nolle[17] the effects of movement of the ears and languid on the laminar jet-flow from the mouth remain unexplored. The organ-builder does not (and cannot) work in such a controlled environment and many investigators have practically negated their findings by altering the proportions of the pipe without correcting its speech and voicing. The art of voicing is a highly skilled one, the proper voicing of pipes should be carried out prior to tests and not during them. This is a fact to which very few investigators seem to attach any importance.

The pipes which fall outside the + or - 5mm error have been noted. It is not clear what the reasons for the great errors of -15mm are due to at pipes C#2 and D#4. It will be seen that the dimensions of the mouth are identical for C - C# and D - D#. The answer is almost certainly to be exhumed in the relationship of the mouth-width to the diameter, which is identical for both pipes. Because the pipes are identical in every respect other than in their physical lengths (this scale was commonly used for Harrison and Harrison case-pipes at the turn of the century), it would seem that the voicing process has forced the pipe into speech at a pitch that it would not have spoken naturally. Although there is much truth in the comment by Herbert and H. John Norman[18] that

> 'To a limited extent, a voicer can make up for deficiencies in scaling by applying slightly higher cut-up when the pipe is underscaled, but the similarity between small-scale cut-up high and a large scale with a low mouth is only superficial'

it is true to say that in the lower frequency-range, the ear cannot distinguish between slight variations in tone-colour.

Philosophical problems of organ design and establishment of scaling criteria

In The New Grove Dictionary of Musical Instruments, Peter Williams has written

> 'Much work still needs to be done on the way pipes are actually made to speak by wind passing through them - work done not so much from the point of view of the physicist as by the builder.'[19]

There has been much work done on most aspects of organ-pipe construction and the sounding-mechanism. Coltman[20] has specifically concerned himself with this latter aspect as has Elder.[21] Fletcher[22] has investigated the same field along with transients and harmonic production. Mercer[23] and Nolle[24] have done significant researches into voicing adjustments and the resultant effect of manipulating pipes in certain ways and the resulting effects on steady-state waveforms. Only the latter work has been of any significance as far as the organ-builder is concerned. This is not a criticism of such research *per se*, as any form of academic study is, by its very nature, highly esoteric. As such, any inter-disciplinary cross-fertilisation has as an inherent problem its subject boundary (mostly a linguistic problem - the language of the physicist is not the language of the musician). The days of the great Greek, Latin and Arabic philosophers and authors has gone, men who were masters of both art *and* science. The positions of the artist and scientist have become entrenched, principally because the states of both Art and Science have become so deepened intellectually, that no ordinary man may be a master of more than one subject and, more specifically, of more than one field. The positions of both artist and scientist have been caricatured on the one hand by the aloof artist, alive only to his sub-concious, nebulous dream-world, unaware of reality, and on the other by the all-seeking scientist, who, in his unquenchable thirst, nay, lust for knowledge sweeps and devours all before him, sacrificing the safety of mankind, spiralling inexorably towards the ultimate destruction of the world.

The organ-building fraternity has begun to see the terrifying significance of the introduction of electricity into the realm of organ-design. Electro-pneumatic action has become the sworn arch-enemy of the mechanical organ as it becomes apparent that the introduction of electricity into organ-building at the turn of the century devastated the progress of the organ as a musical instrument and gave rise to the excesses which characterise the organ of the inter-war years.

Most of the acoustical investigations into the organ flue-pipe (little has been done on reeds, as yet) have, naturally, been concerned with the production of mathematical models which explain the *modus operandi* of pipe speech. Some work (particularly that of Nolle) confirms the long-held opinions of the organ-builder and as such is of no direct help to the craft, whilst work such as that by Sundberg[25] makes such investigation unpopular with the mechanical organ-builder, particularly when it is concerned with the reproduction of the pipe-organ's sound through electronic circuitry.

There are those in the organ-building world who would copy old instruments, particularly pipe scalings; the historical copy never has the sweetness of tone of the original instrument[26] and its resultant construction can be a terrifying experience to the player.

Flentrop's introduction of a slightly variable wind-pressure at Evora Cathedral is an admirable move to authenticity. Such developments remind us that an organ should be planned so as to remind the player that it is essentially a wind instrument.[27] The only authentic wind supply is, of course, that generated by hand-pump. The introduction of a calculated 'dip' in the wind source generated by an electrical fan is a compromise, but then who would doubt that the introduction of electricity in terms of raising the wind in an organ has not been beneficial? The copying of console-dimensions from one instrument to another without taking note of subtle morphological differences between the stocky eighteenth-century Teuton and, say, the twentieth-century Mancunian may be the next area for revision. These attempts to help the organist get into the shoes of different periods of organ-building history answer no questions at all. The originals are still there to be examined without making imperfect copies of them.

The copying of older pipe-dimensions without taking notice of the change of acoustic environment from the originals to a new organ is unsatisfying, unproductive art. What is it that is to be copied from a particular organ?

Components of an instrument, perhaps re-built by several organ-builders and culminating in a masterpiece? If the historical copy is to assert any influence as an active force in organ-building, let it not be a copy of an instrument built or amassed in a certain acoustic location, but rather one which attempts to *solve* the problems which would have faced the builders in the new situation. The result must be a musical instrument in its own right. If the organ is to continue to evolve it must not be hampered by conditions which ultimately confine the sound of an organ to a particular decade of the organs of a builder whose work is considered worthy of emulating. Only when assimilation (from a scientific point of view if necessary) of evidence which shows what an organ-builder of a past age *might* have done in a given acoustic environment in his solution to scaling and voicing will the designers and organologists of today be able to theorise as to how that builder might have approached another location. Drawing on the best of revered organ-builders and thus allowing the organ-builder of today to create new instruments based on the collective experiences of older generations is the aim of the reform which has not been fully explored as far as scaling is concerned.

The most significant contribution to the question of scaling from a scientific point of view has been the investigation carried out by N.H.Fletcher in his *Scaling Rules for Organ Pipe Ranks*,[28] in which he makes a brief study, based on Mahrenholz,[29] of pipe scalings, giving a formula for Mediaeval pipe-scales, where the diameter of one pipe is identical to that of its adjacent pipe, as

$$D=D_0 \qquad 3.10$$

where D is the diameter of a pipe of length L sounding the fundamental frequency V_1
and D_0 is the diameter of a pipe of length L_0 sounding the fundamental frequency V_0
D_0, L_0 and V_0 refer to some reference pipe within the rank.

The scale doubling on the octave in the ratio is given as

$$D= D_0(V_0/V_1) \qquad 3.11$$

and the other scale ratios as

$$D= D_0(V_0/V_1)^x \qquad 3.12$$

In this last equation, x is chosen such that 2^x is a rational fraction (*i.e.*, one which may be expressed by two integers in terms of a fraction) principally because pipe-scales were developed in an arithmetical rather than an algebraic manner.[30] From the point of view of tonal balance, a ratio of 1.78 (5/6, halving on the fourteenth note or fifteenth semitone step) is well known to yield too loud a volume in the bass: relative loudness is determined not only by sound-pressure level, but also by the characteristics of human hearing.[31] The perception of 'equal loudness' falls in the higher frequency range by about 3dB per octave on average,[32] and Fletcher has shown that a rank constructed in the ratio of 1.78 is too loud in the bass because it varies by about 6dB per octave in comparison. The pipe-scale sets a limit to the amount by which the voicer can adjust the tonal output of the pipe, but the principle here is that a pipe must be made to produce a natural sound from its scale and construction and therefore not forced into speech where its scale does not warrant the sound that the voicer is seeking.

Fletcher sees the objective for a scaling 'rule' in the following way:

> 'To determine an appropriate scaling rule for a pipe rank we must try to achieve two objectives: an equal or appropriately graded harmonic development and an equal loudness throughout the rank.'[33]

Unfortunately, neither equal loudness or equally graded harmonic development throughout the compass are considered a necessary pre-requisite for a rank of pipes. It is now more common for the pipe-dimensions to be so calculated that the ratio between pipe mouth-width and circumference varies as does the cut-up as it is felt necessary to vary the output of the pipe to match the acoustic of the building. Many organ-builders today have moved away from the idea of the constant or fixed scale to the so-called fixed-variable scale in which, whilst the basic logarithmic pattern is retained and the halving ratios change from octave to octave, (depending upon how the organ-builder views the tonal structure, not only of the instrument as a whole, but also of the individual ranks), the geometrical series is destroyed by adding or subtracting a constant. Such scales, when plotted against the Toepfer *Normalmensur* are of a siusoidal type, and not of the more usual straight line type. The other method used in the production of scales is the free-variable type, in which the scale is drawn and measured but not calculated. Scale graphs drawn in this way, when plotted against the *Normalmensur* may be translated by the use of the *Rechenschieber für*

Orgelpfeifen, the organ-pipe scale slide-rule devised by Richard Rensch. At the turn of the century there was a growing awareness that the constant scales produced by Toepfer's theory were too uncompromising. Gray wrote in 1913

> 'Nowadays I understand that even Toepfer's scale is considerably modified.'[34]

The scaling of a rank, if wide, becomes fluty, or purer in tone quality, and if narrow of a stringy character. Thus an organ-builder can make particular scales of slightly variable quality in the rank. Downes relates how the old 'perfectionist school of voicing' operated:

> 'Holding treble e, he proceeded *legatissimo* to f, and was only finally satisfied when the upper pipe 'followed' perfectly and exactly, aided by various voicing procedures. The whole stop? It sounded smooth and in a way sweet; but musically speaking, characterless. Every vestige of 'personality' had been scrupulously removed: it was absolutely free of harshness! This in any case was contrary to nature: in a real musical instrument, whether string or wind, and even when modern makers have *tried* to 'smooth them out' , the timbre alters completely as one plays through its tonal range: consider the flute. clarinet, bassoon, trombone, viola, for instance, when played straightforwardly, *p*, *mf* or *f*. Hence the utter futility of trying to give an organ-stop a uniform tone-colour throughout its compass - but this was, at the time, the unquestioned ideal of a *perfectionist* voicer.'[35]

The lesson that has been learned from Toepfer's use of a geometric proportion in the calculation of pipe-scales is that the use of such a regular scale is neither desirable nor required in any situation in organ-building. This, of course, does not preclude the use of logarithmic scales for intervening semitone steps where the halving-progression changes at different rates as the scale ascends. The use of the constant scale has been universally rejected by the reform movement.

Michael McNeil has posed a 'Theory of Voicing and Scaling Flue Pipes'[36] in which he identifies the complicating factors in deciding a scale for a building as

'1) the frequency response of a large or small acoustic and

2) the absorbency of the room surfaces'.[37]

Since the frequency response of a building is determined by the absorbency of the surfaces *in* the building, it seems unnecessary to consider both aspects in the present study. Wallace Sabine's law for reverberation time in a building is given as

$$T = 0.049 \frac{V}{A} \qquad 3.13$$

where T = reverberation time
V = volume of the room
A = total absorption in the room (in sq. ft.)
(The constant is calculated from Imperial measurements)
and, A is given by

$$A = Sa \qquad 3.14$$

where S is the square feet of some material of absorption coefficient a.

The total absorption is given as

$$A = S_1a_1 + S_2a_2 + S_3a_3 + \ldots S_na_n \qquad 3.15$$

This formula is well documented and most acoustic work is based on calculations such as these. The frequency response of a building has not been investigated in much depth in the field of organ design with the exception of Lottermosser and Mayer[38] whose work examines extant examples, although not in the form given in chapter 4 which contains an example of how the frequency response of a building might be interpreted for producing pipe-scales.

McNeil gives his theory of scaling in the few following extreme cases

ACOUSTIC	BASS Absorption	TREBLE Absorption	SCALING METHOD
small, live			low pressure narrow bass narrow treble small Praestant
small, dead	X		low pressure wide bass narrow treble small Praestant
large, live		X	high pressure narrow bass wide treble large Praestant
large, dead	X	X	high pressure wide bass wide treble large Praestant

which represents a set of criteria for interpreting the acoustics of a building into a pipe-scale. There are other features which must be considered, but these are discussed in chapter 4.

CHAPTER 4

A METHOD OF DESIGNING A PIPE-SCALE

In order to go some way to designing pipe-scales to match the acoustic environment, it was necessary to find a building in which it would be convenient either to compare existing scalings and contrast the diameter halving ratios with the way the building reacted to them on both a subjective and an objective level or to design a set of theoretical pipe-scales for a building. By chance, the parish church of St. Oswald in Durham was open to such an experiment, since the church had been badly burned by a fire in 1984 in which the organ was completely destroyed. Plans were afoot to install a new organ once the building had been put into good repair. The organ-builder who won the contract was Peter Collins of Redbourn , Hertfordshire.

The first step was to develop a mode of acoustic analysis most suited to the nature of the final calculations. A simple gunshot was discounted as an effective method of determining details of the acoustic, as it was felt that a Fast Fourier Transform of the gunshot would reveal nothing other than an absolute reverberation time for the building.

A more detailed survey of the acoustic was sought by sounding sine waves at known frequencies in the building from a loudspeaker mounted as high as possible in the church to simulate the position of the organ. The results were encoded on a two-channel digital recorder. The first channel contained the recorded sound from the church when the sine wave was turned off using the switch; the second channel recorded a 'click' which indicated the exact moment that the sound had been turned off and the moment that the reverberation began in the building.

There were many inherent problems in this experiment, one of which was that of traffic noise and its effect on the recording. The lowest frequencies on the instrument were to be in the order of 32 Hz for the 16-foot stops. For practical reasons it became impossible to perform this test during the night and it had to be done during daytime (out of rush-hour) using repeated tests where traffic noise interfered with an individual recording. Filters were applied once the frequencies were over 75Hz and 150Hz but below these frequencies the background noise left the lower frequency range valid down to -30dB.

The height of the proposed organ was (at lowest) 10 feet above the floor, being mounted on a balcony supported by four columns. As no work had started on the organ or gallery at that time and the proposed site was still occupied by choir stalls, the loud speaker could only be raised to a height of *almost* ten feet, representing the base of the proposed Chaire organ case.

The calculation of an accurate absorption coefficient was another problem, in that there were no accurate measurements of the proportions of the church. With the proposed removal of so many stalls at the back of the church to accommodate the organ and the construction of such a huge piece of furniture which effectively excluded the tower from

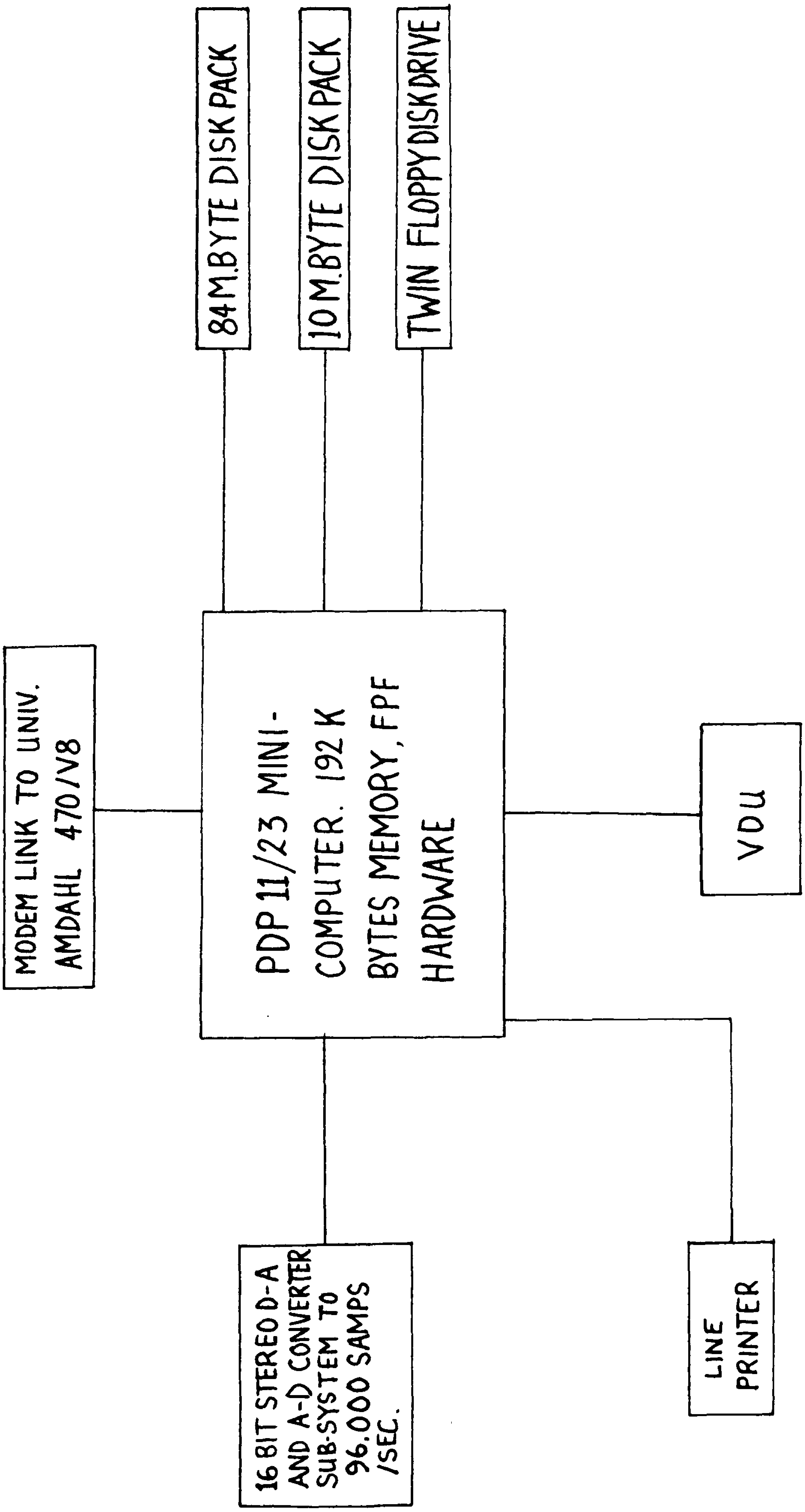

84 M.BYTE DISK PACK
10 M.BYTE DISK PACK
TWIN FLOPPY DISK DRIVE
MODEM LINK TO UNIV. AMDAHL 470/V8
PDP 11/23 MINI-COMPUTER. 192 K BYTES MEMORY, FPF HARDWARE
VDU
16 BIT STEREO D-A AND A-D CONVERTER SUB-SYSTEM TO 96.000 SAMPS /SEC.
LINE PRINTER

Fig. 44

receiving sound directly from the organ (which obviously was to face the other way in the building), there was no guarantee that the calculation of an absorbtion coefficient (and thus any other form of acoustic analysis) would be true of the building after the alterations and installation of the organ. After much consideration, any theoretical attempts to simulate the effect of the installation of the organ were discounted and any results should be considered in light of this.

A recording was made for each frequency of the tempered scale from 30 - 8000 Hz. Each recording was fed into a PDP11 mini-computer described in fig. 44. A Fortran program was used to locate the 'click' from the switch encoded on the first channel and the decibel decay from the second channel was monitored.

The three-dimensional plotting was performed using the SURFACEII graphics system on the University's Amdahl 470/V8 main-frame computer. Arithmetic averaging of adjacent Z values in the grid matrix was carried out. The purpose of this smoothing was to eliminate undesired interference, 'noise', or small-scale variability present in the original grid. A process of unweighted smoothing was used, the central point being multiplied by a specified parameter and averaged with the unweighted values of the nearest specified number of points in the matrix to produce a new value for the Z axis. The graphs are viewed from an angle of 135 degrees rotation (azimuth) from the south and at an elevation of 25 degrees - these two angles gave the best viewing point for the exposure of detail on the acoustic landscape. The configuration of the X-Y-Z axes are described in figure 45. The graphs are numbered sequentially from 0.4 to 2.2 seconds in the first group (figures 47 to 64). In this first group the time interval is gradually increased along the Z axis and each graph has that axis compressed as the time scale increases to maintain the same dimensions for each plot. In the second group (figures 65-73), the Y axis is gradually lowered such that the cut-off point increases from a -20dB minimum to -50dB. The following frequency chart will be of use in pin-pointing frequency ranges as the X-axis is labelled in stop-pitch nomenclature (16′, 8′, 4′, etc.).

Pitch	Frequency (Hz)
16′	32.7
8′	65.4
4′	130.8
2′	261.6
1′	532.3
1/2′	1046.5
1/4′	2093.1
1/8′	4186.1
1/16′	8372.2

The determination of an absolute reverberation time was not considered to be directly helpful, since that absolute corresponds to a long reverberation in one or more band regions of the aural spectrum. These plots are arranged such that the rate of decay in various band regions are clearly visible. Of immediate significance is the very rapid decay of the highest frequencies. A resonance peak can be seen at about 3500 Hz which falls to a pronounced trough between 4000 and 8000 Hz, which, at its centre, has decayed to -30dB after 0.4 seconds has elapsed (fig. 46).

key to interpretation of three-dimensional plots

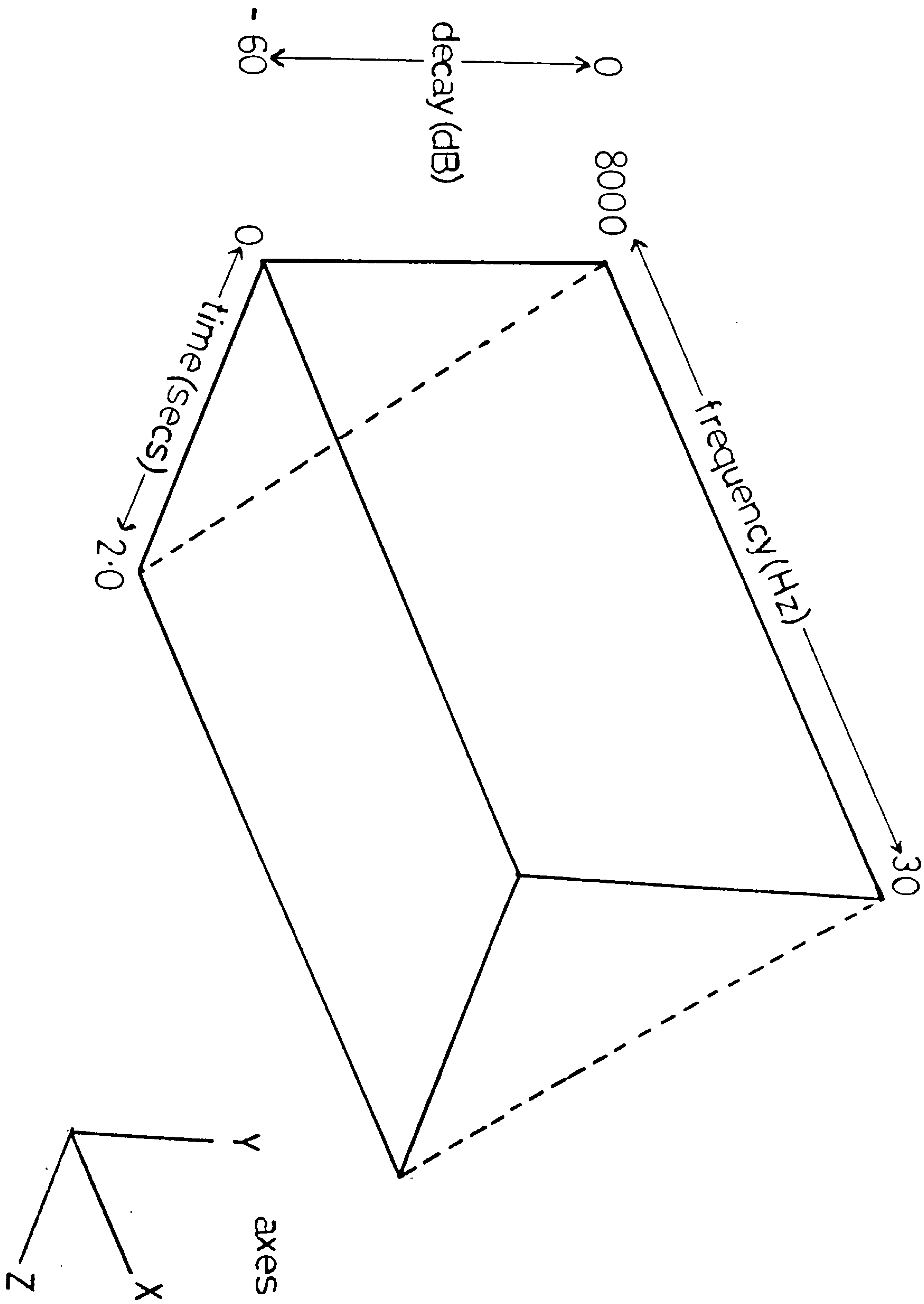


Fig. 45

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 0.4 SECONDS

PLOT NO. 2 DATE 02-17-87 TIME 10:17:56

AZIM = 135.0 ELEV = 25.0 DIST = 10000

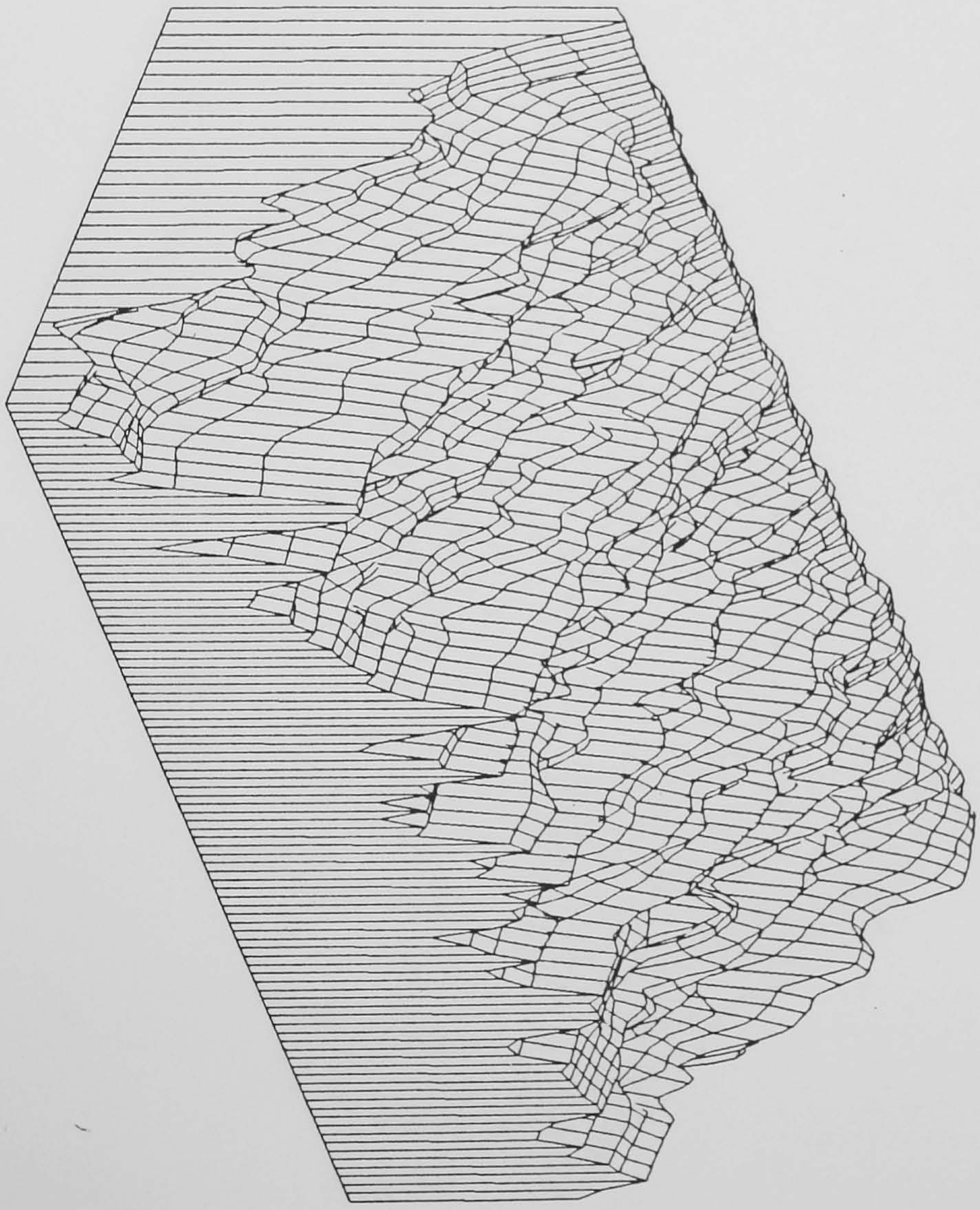


Fig. 46

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 0.5 SECONDS

PLOT NO. 2 DATE 02-17-87 TIME 11:04:56

AZIM = 135.0 ELEV = 25.0 DIST = 10000

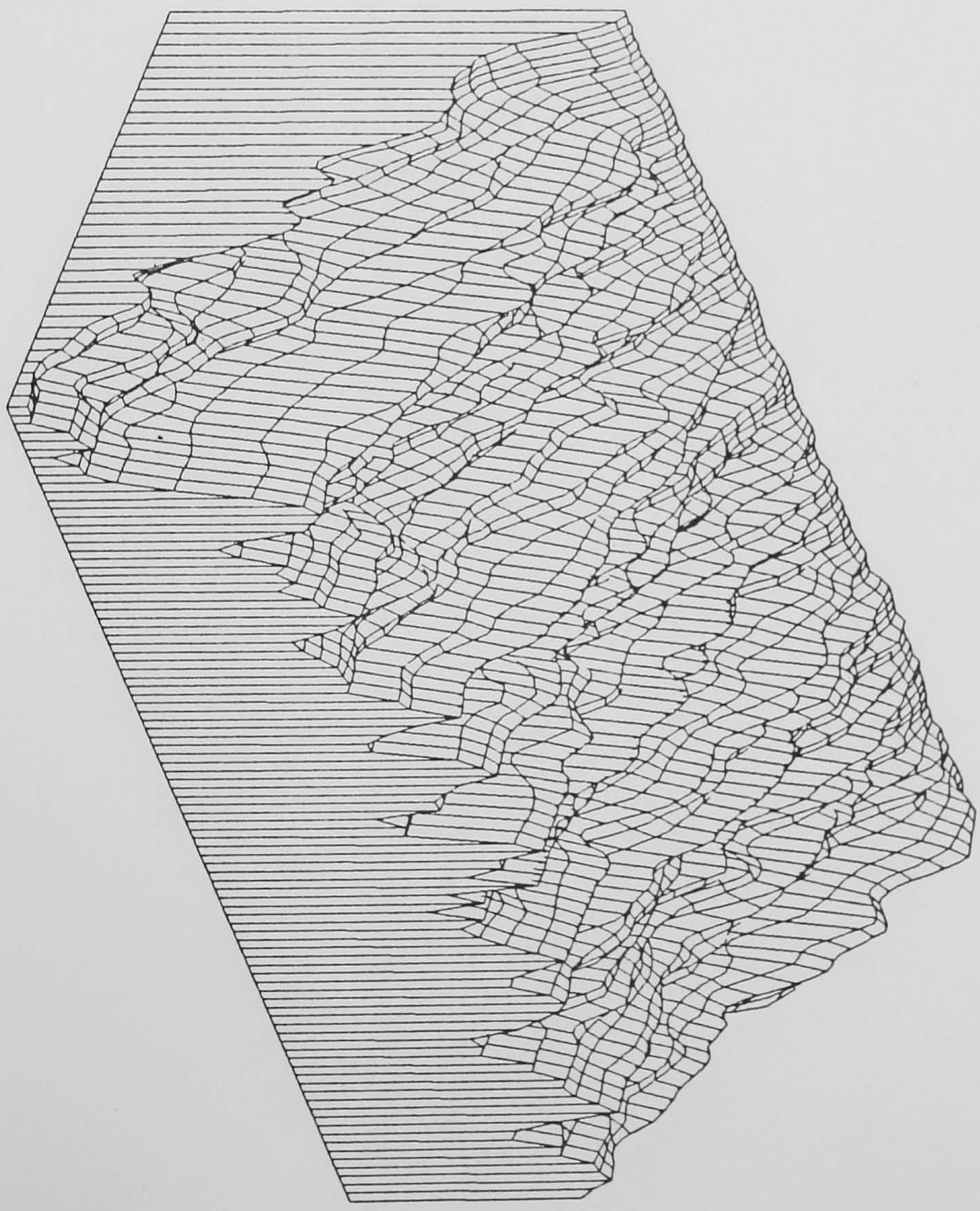


Fig. 47

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 0.6 SECONDS

PLOT NO. 2 DATE 02-17-87 TIME 11:38:08

AZIM = 135.0 ELEV = 25.0 DIST = 10000

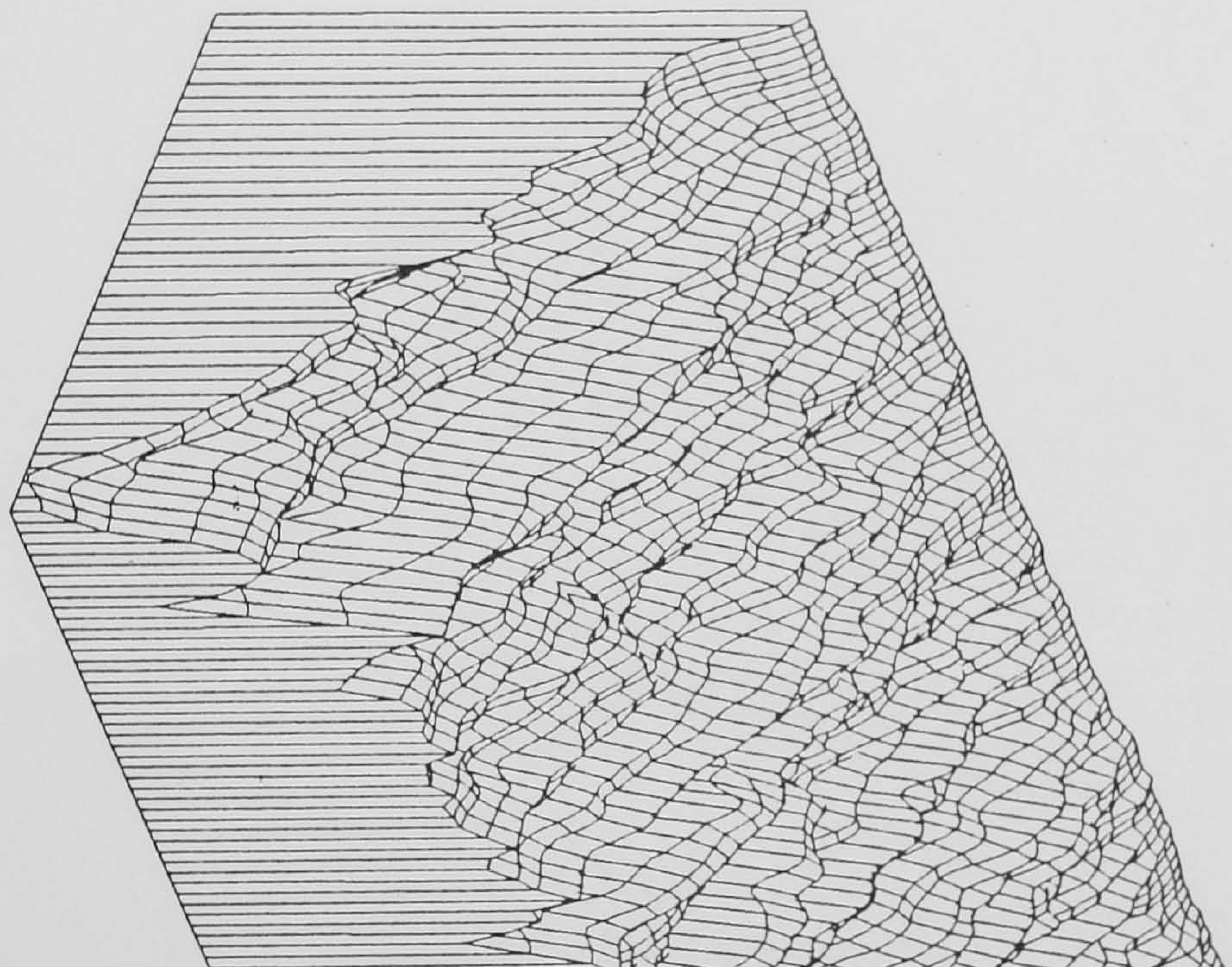


Fig. 48

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 0.7 SECONDS

PLOT NO. 2 DATE 02-17-87 TIME 12:32:26

AZIM = 135.0 ELEV = 25.0 DIST = 10000

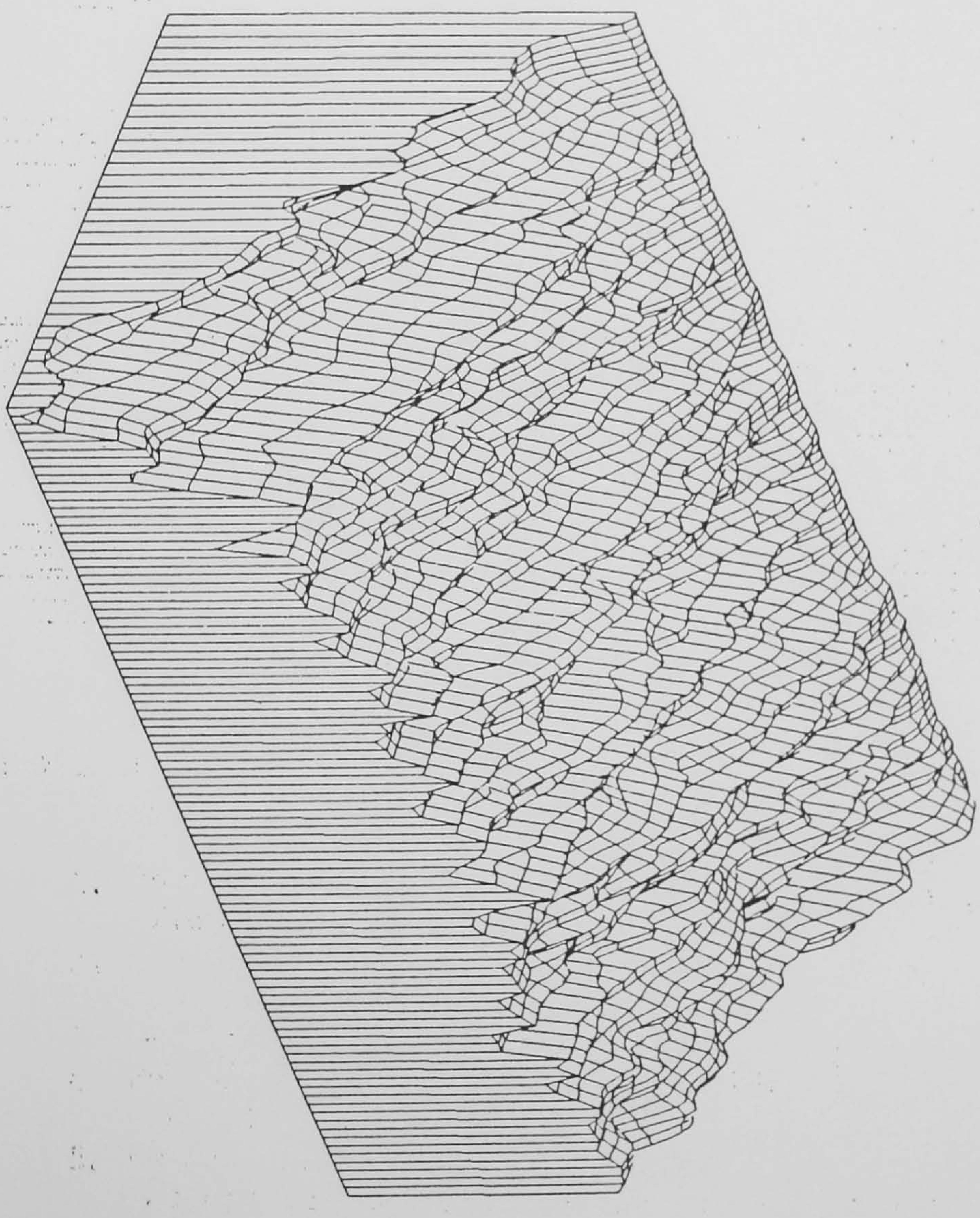


Fig. 49

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 0.8 SECONDS

PLOT NO. 2 DATE 02-17-87 TIME 16:22:52

AZIM = 135.0 ELEV = 25.0 DIST = 10000

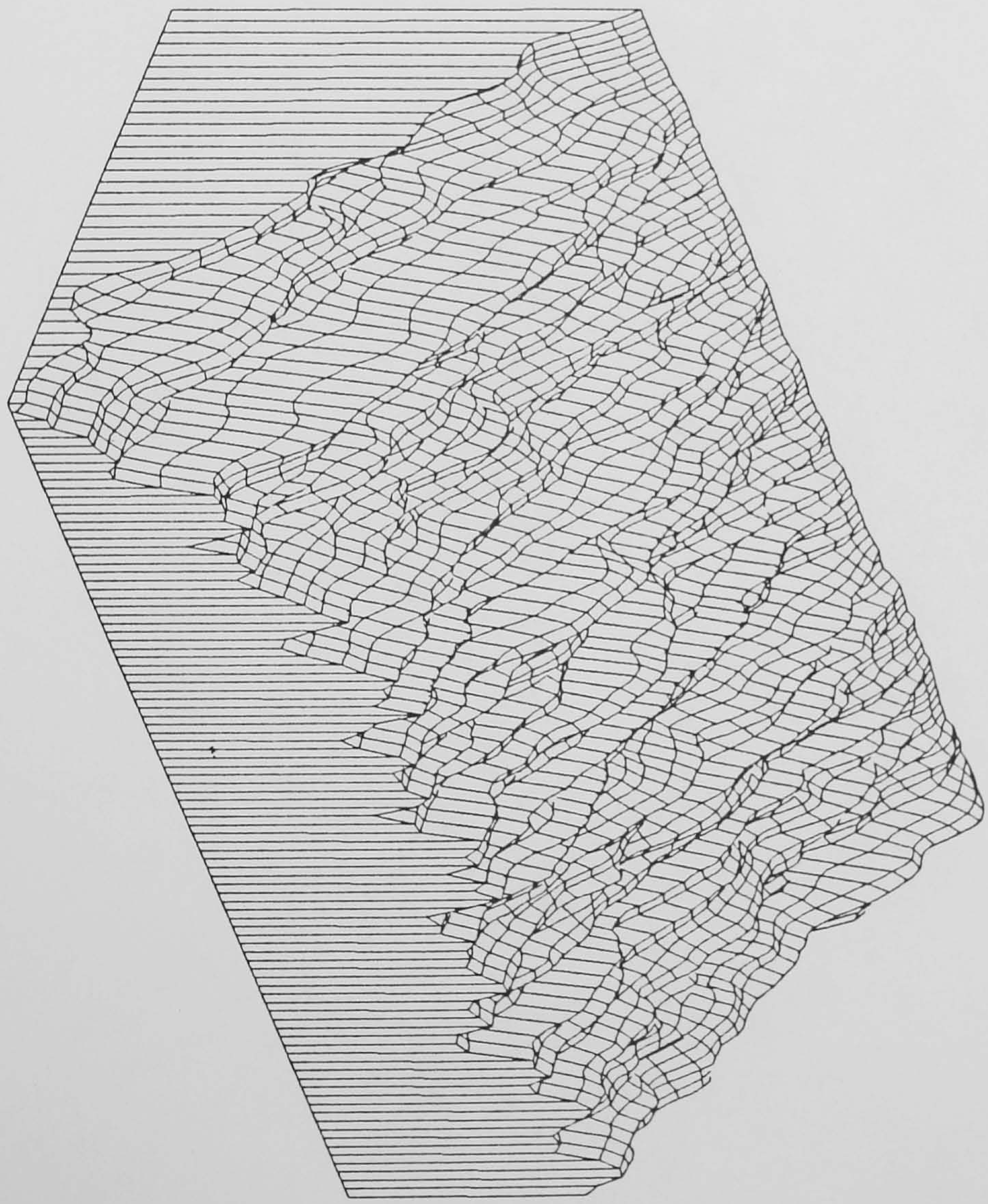


Fig. 50

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 0.9 SECONDS

PLOT NO. 2 DATE 02-17-87 TIME 16:47:02

AZIM = 135.0 ELEV = 25.0 DIST = 10000

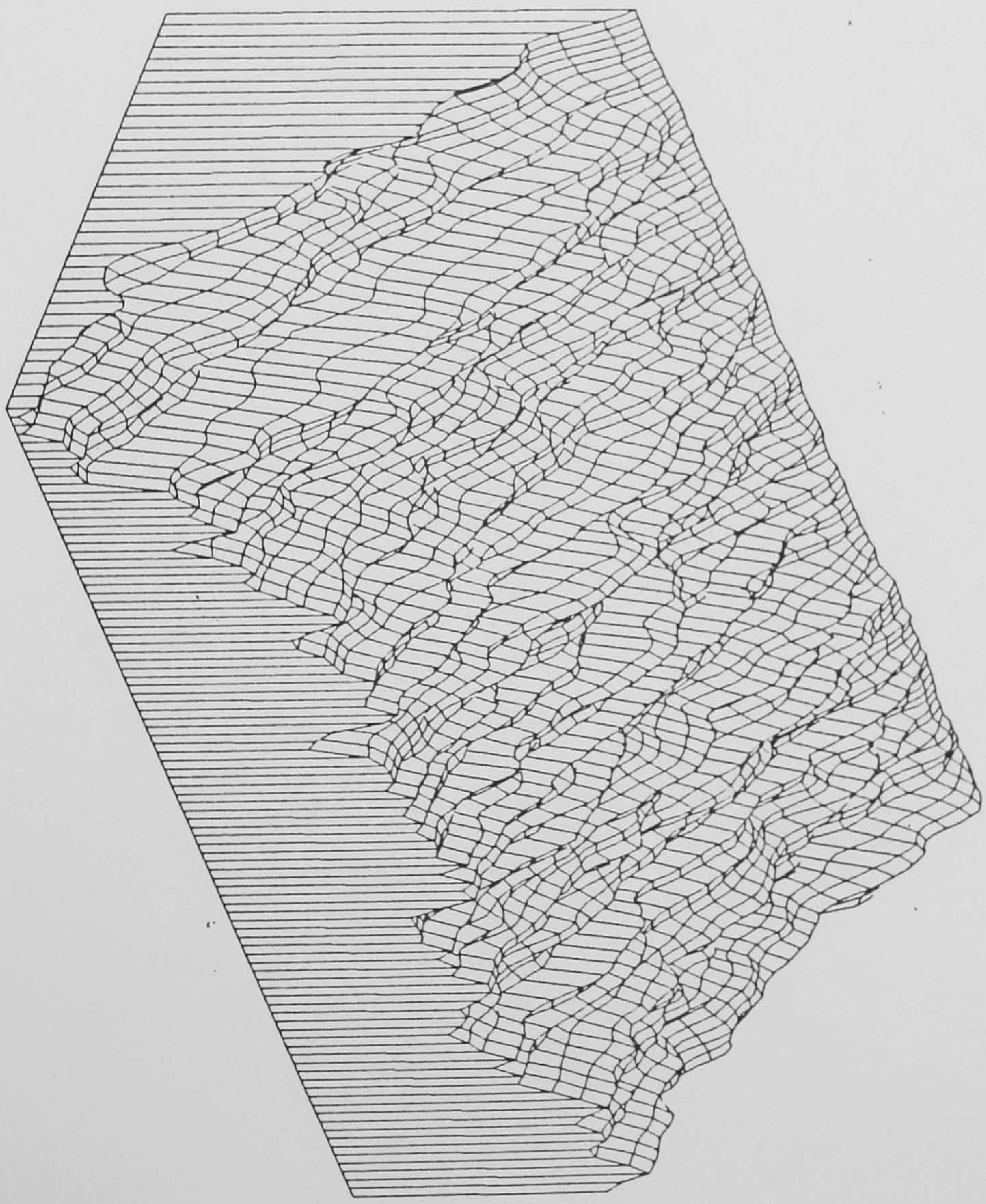


Fig. 51

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.0 SECONDS

PLOT NO. 2 DATE 02-10-87 TIME 10:52:31

AZIM = 135.0 ELEV = 25.0 DIST = 10000

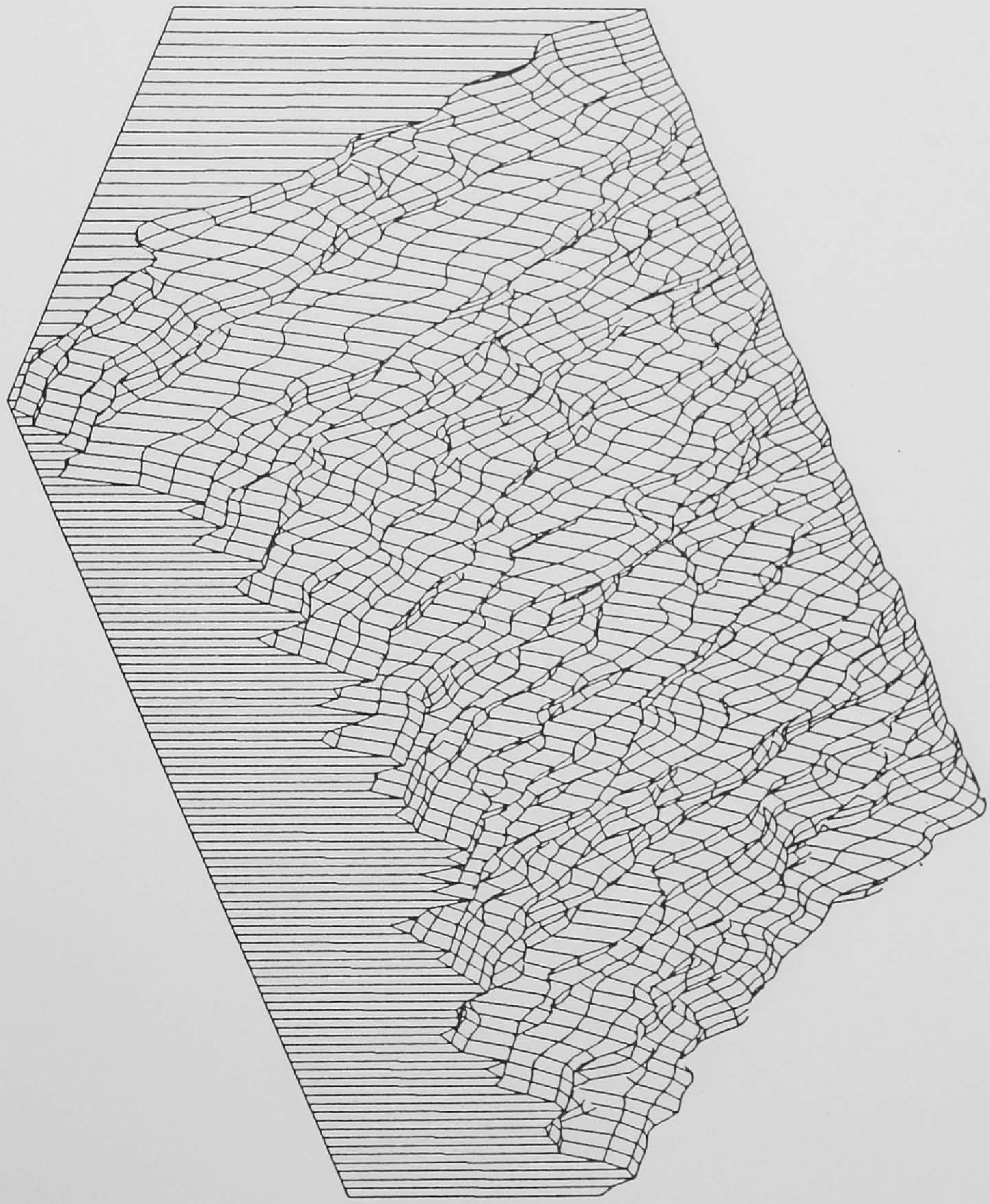


Fig. 52

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.1 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 08:56:51

AZIM = 135.0 ELEV = 25.0 DIST = 10000

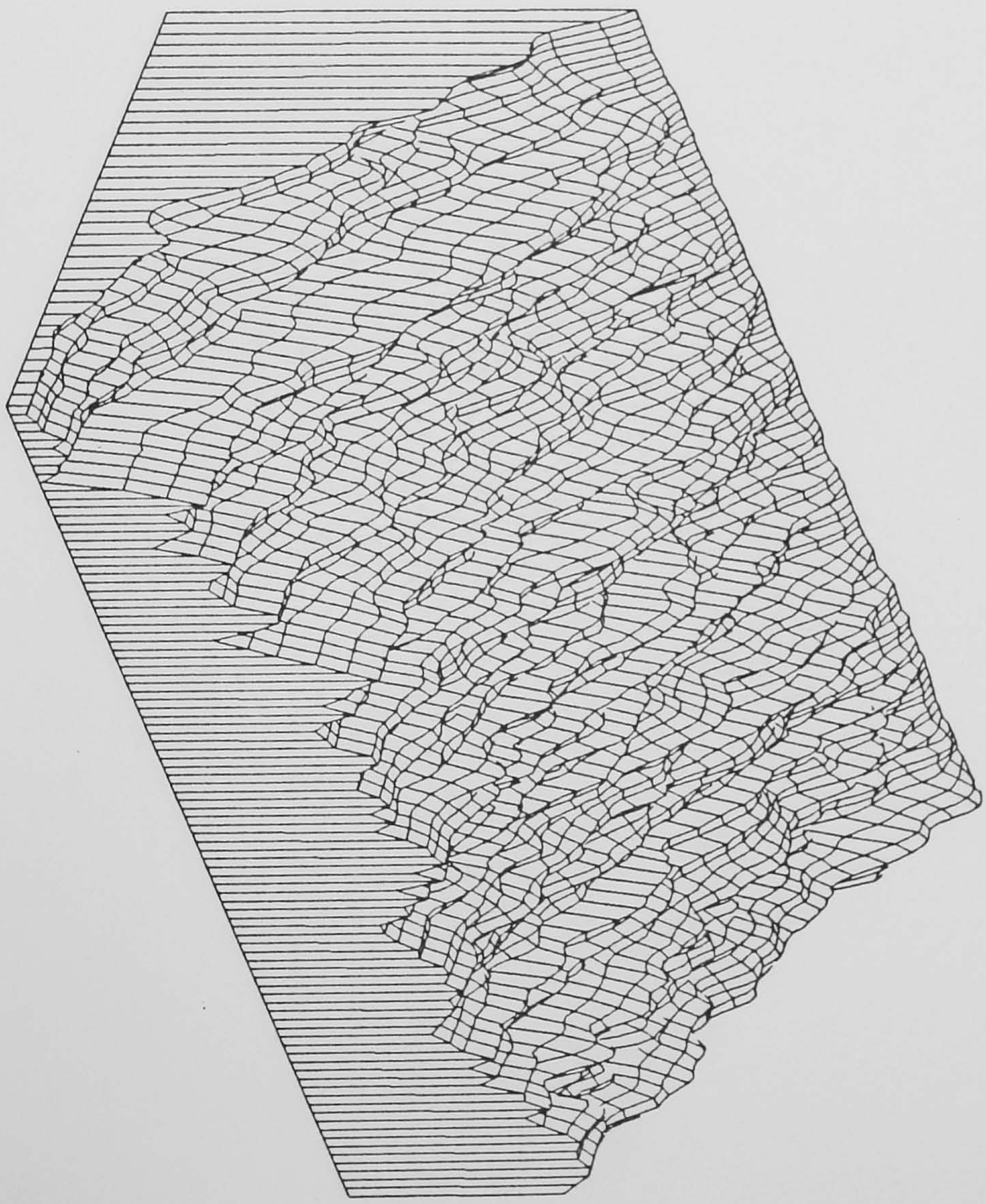


Fig. 53

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.2 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 09:04:31

AZIM = 135.0 ELEV = 25.0 DIST = 10000

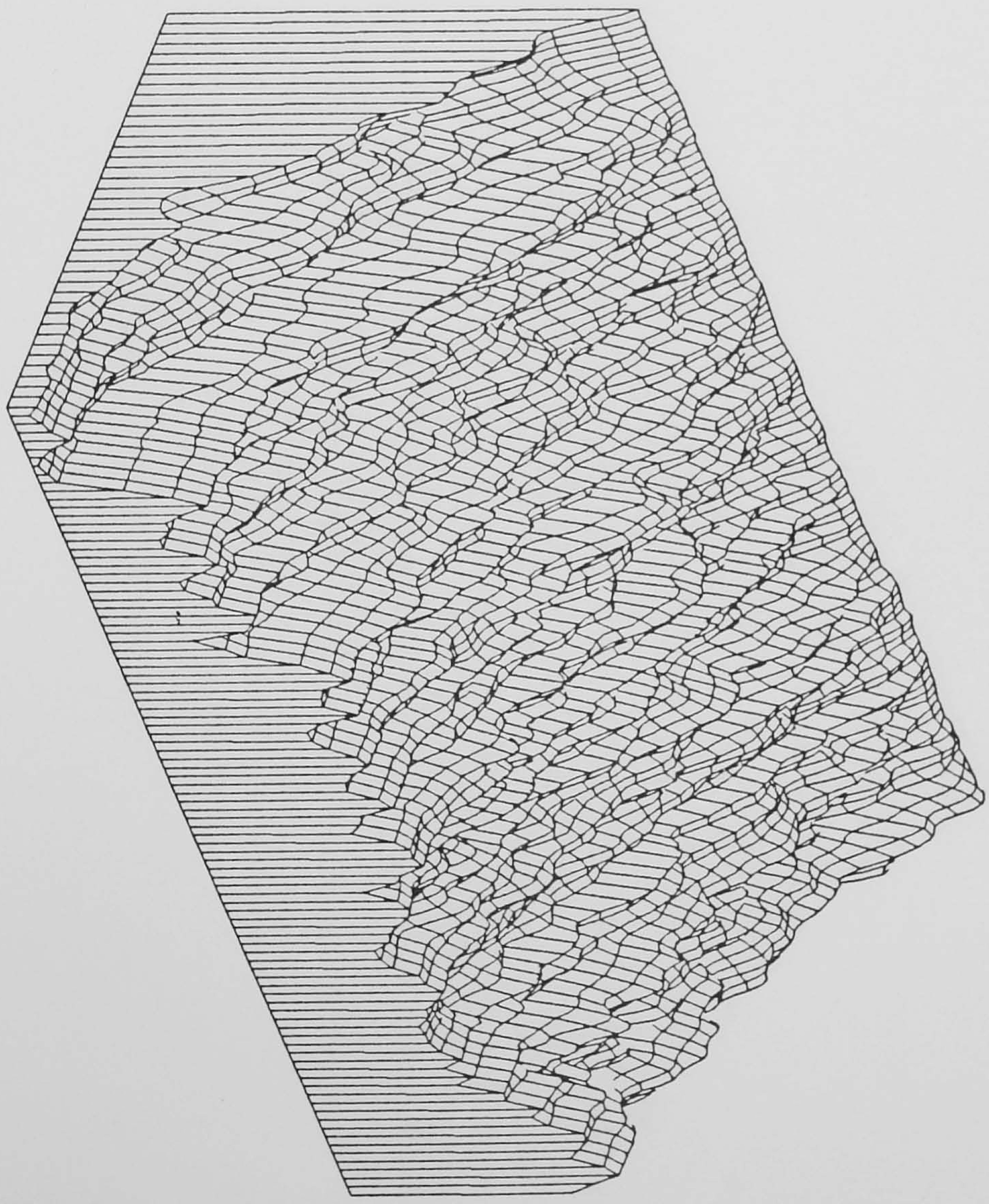


Fig. 54

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.3 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 09:12:19

AZIM = 135.0 ELEV = 25.0 DIST = 10000

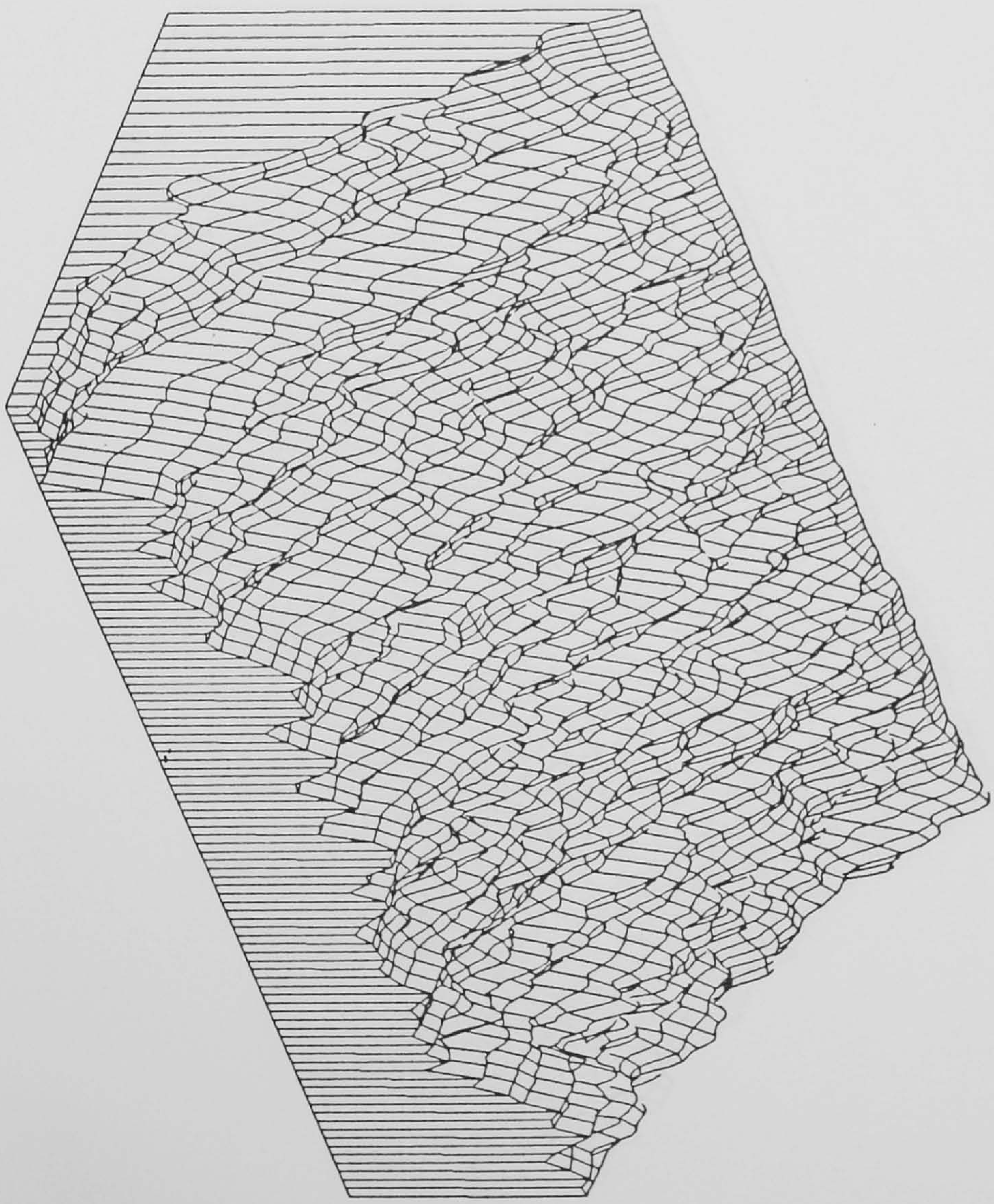


Fig. 55

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.4 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 09:20:55

AZIM = 135.0 ELEV = 25.0 DIST = 10000

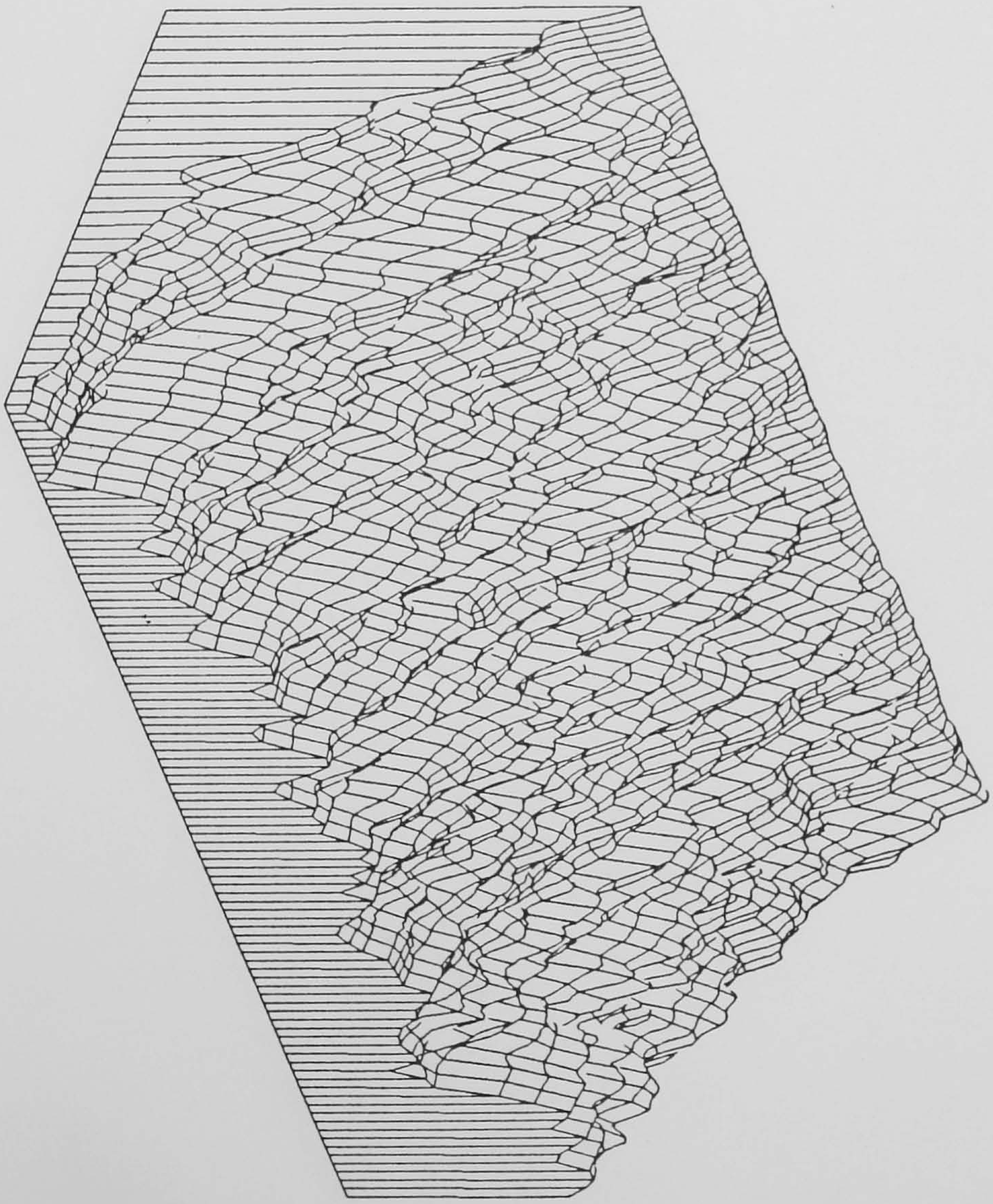


Fig. 56

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.5 SECONDS

PLOT NO. 2 DATE 02-10-87 TIME 12:01:37

AZIM = 135.0 ELEV = 25.0 DIST = 10000

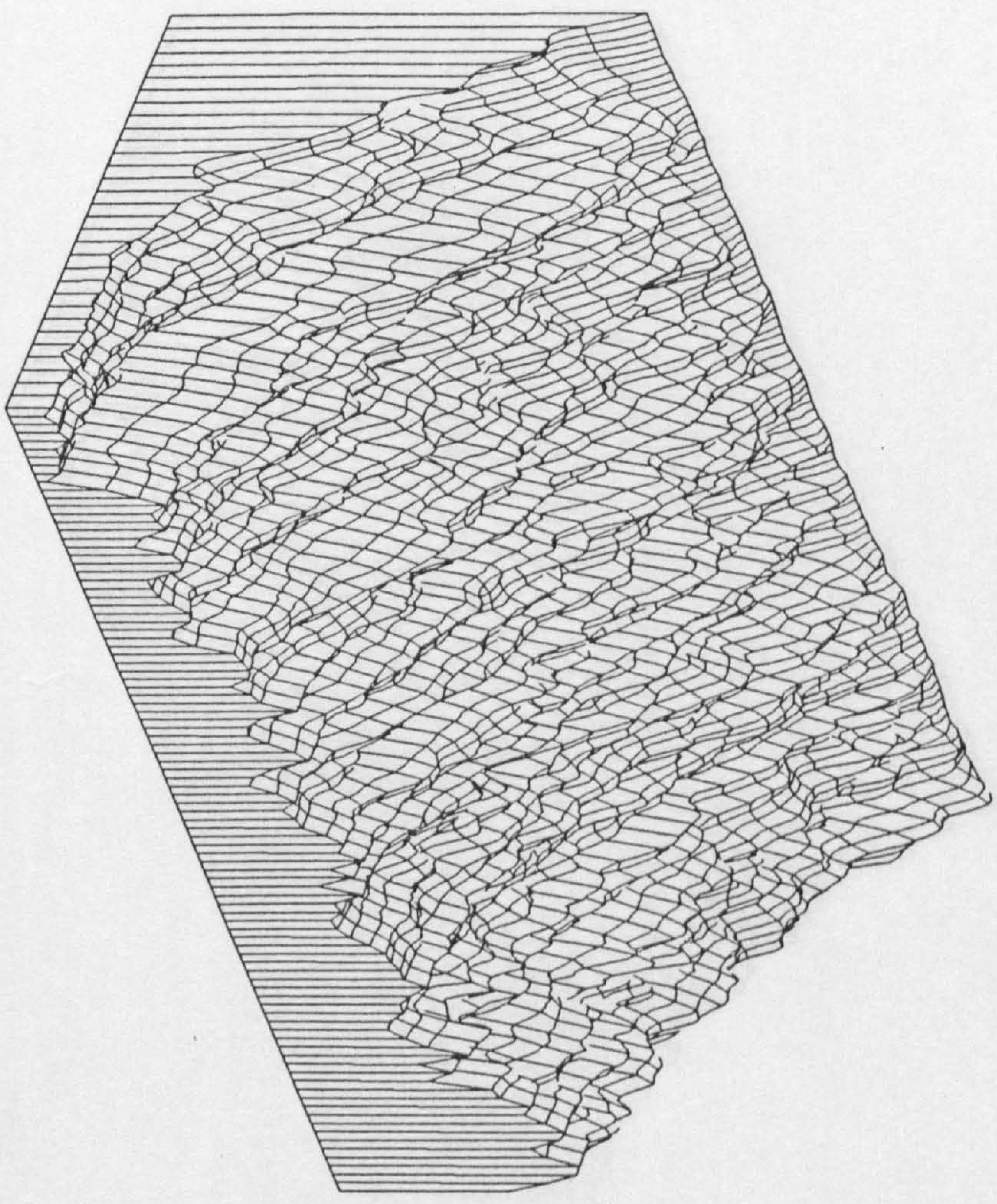


Fig. 57

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.6 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 09:30:02

AZIM = 135.0 ELEV = 25.0 DIST = 10000

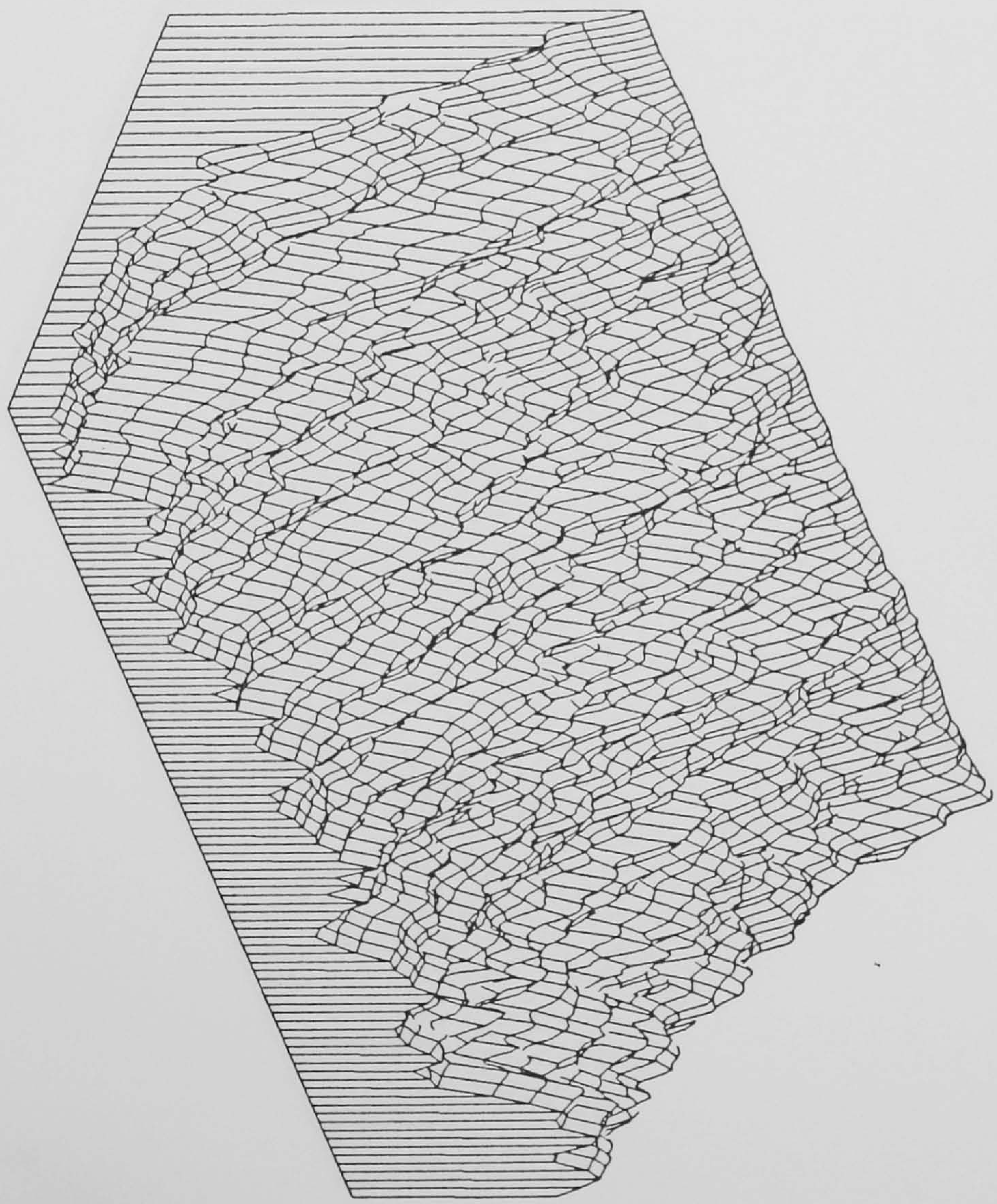


Fig. 58

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.7 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 09:43:45

AZIM = 135.0 ELEV = 25.0 DIST = 10000

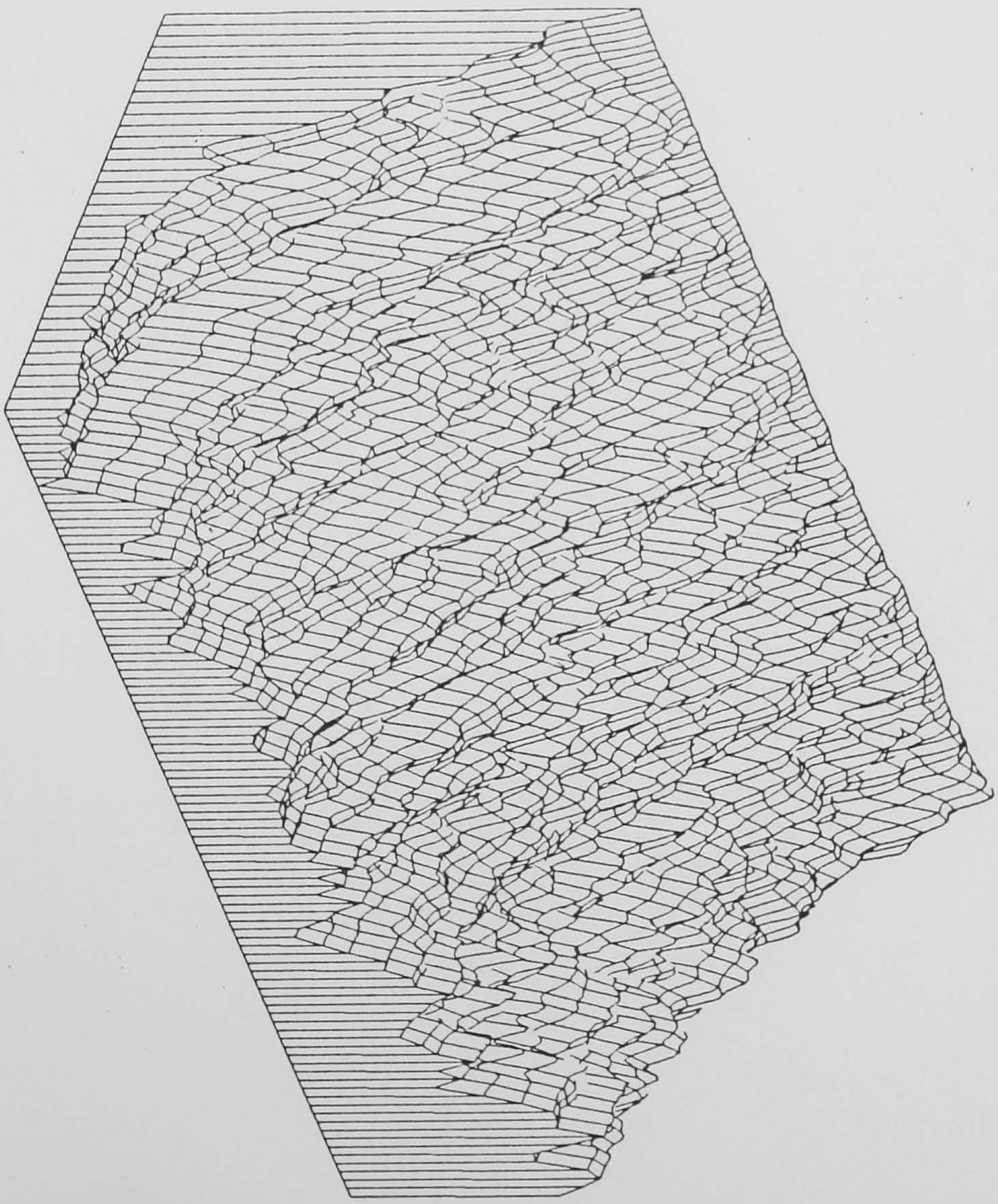


Fig. 59

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.8 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 11:03:43

AZIM = 135.0 ELEV = 25.0 DIST = 10000

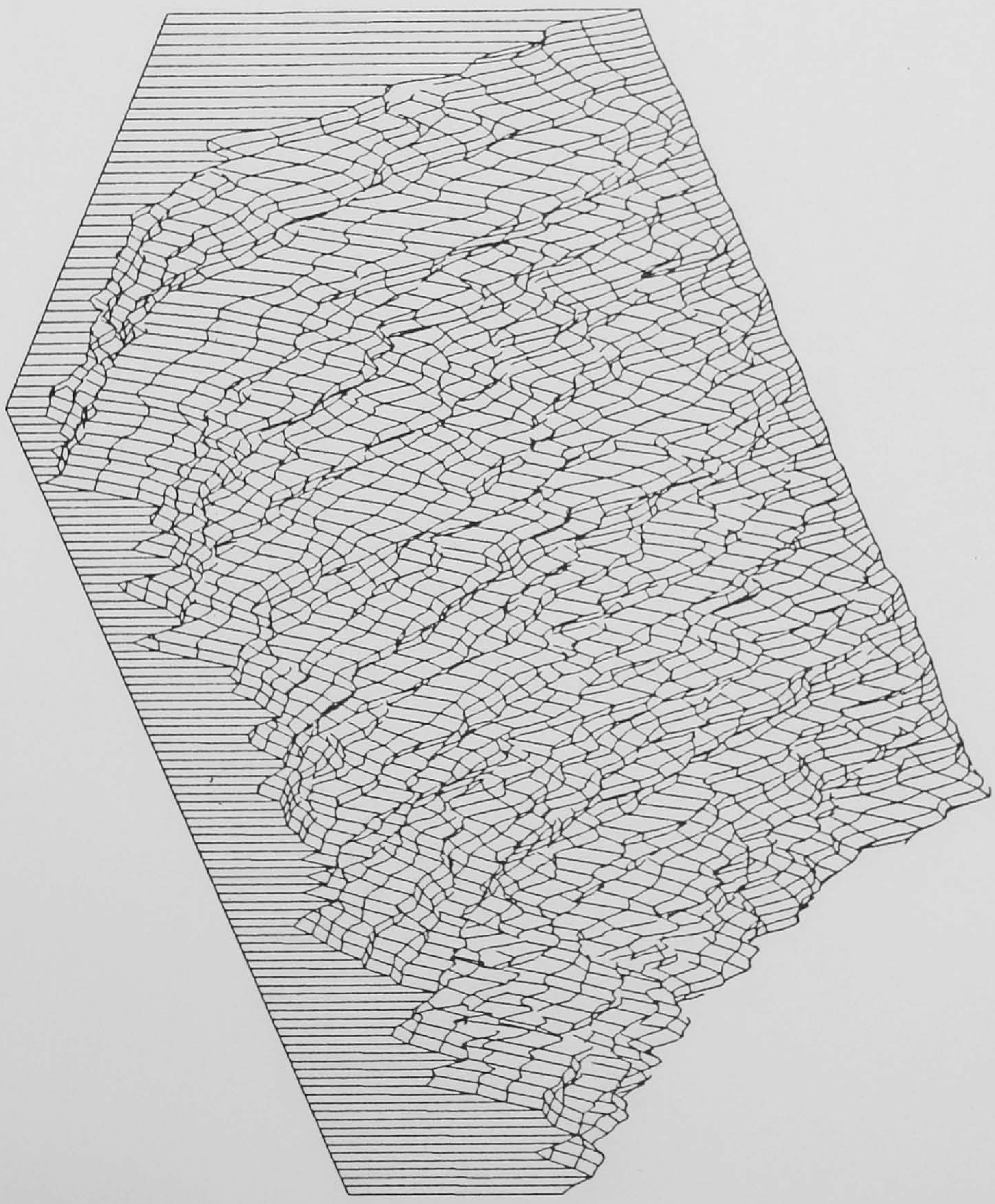


Fig. 60

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 1.9 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 11:24:30

AZIM = 135.0 ELEV = 25.0 DIST = 10000

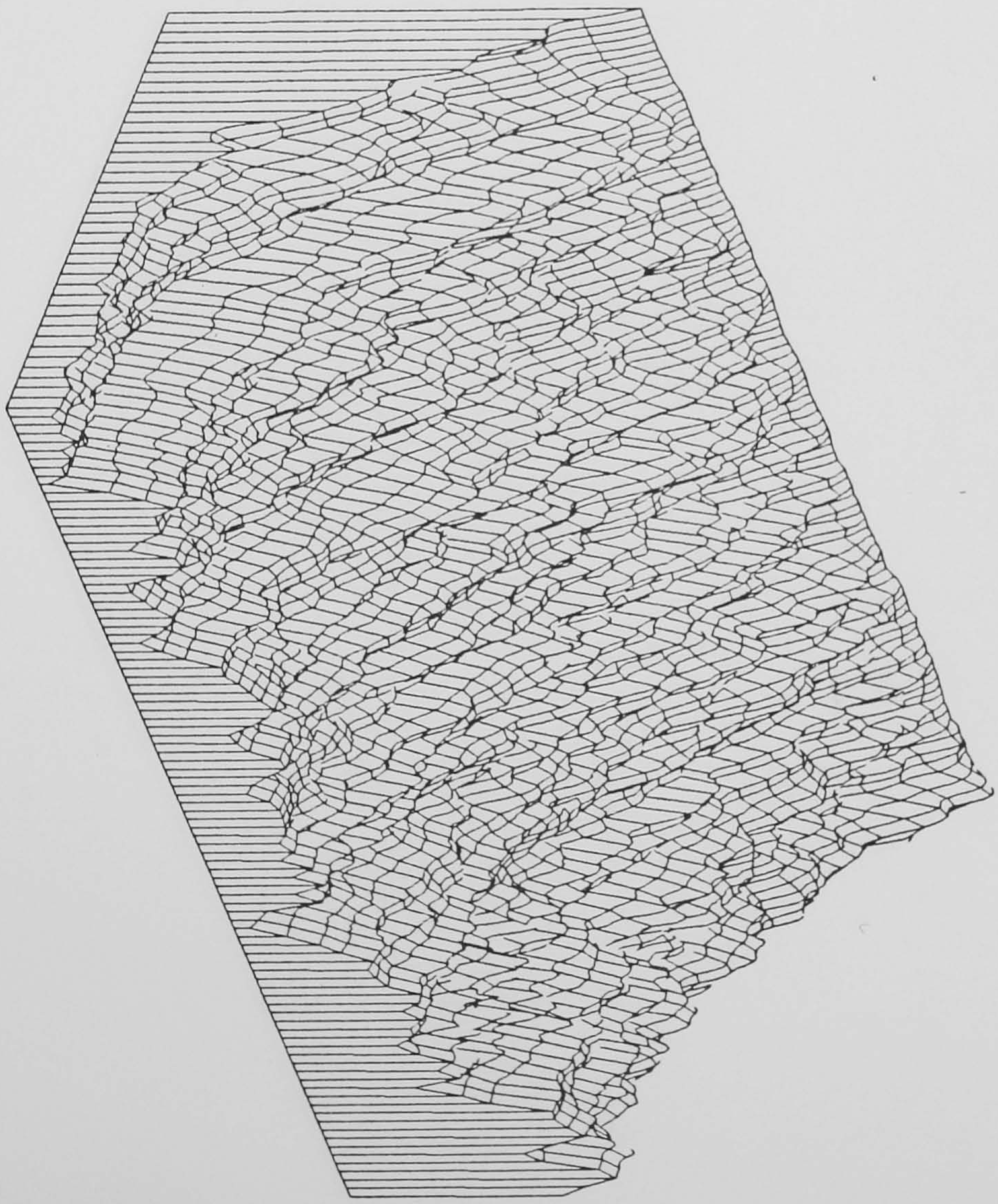


Fig. 61

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 2.0 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 11:40:16

AZIM = 135.0 ELEV = 25.0 DIST = 10000

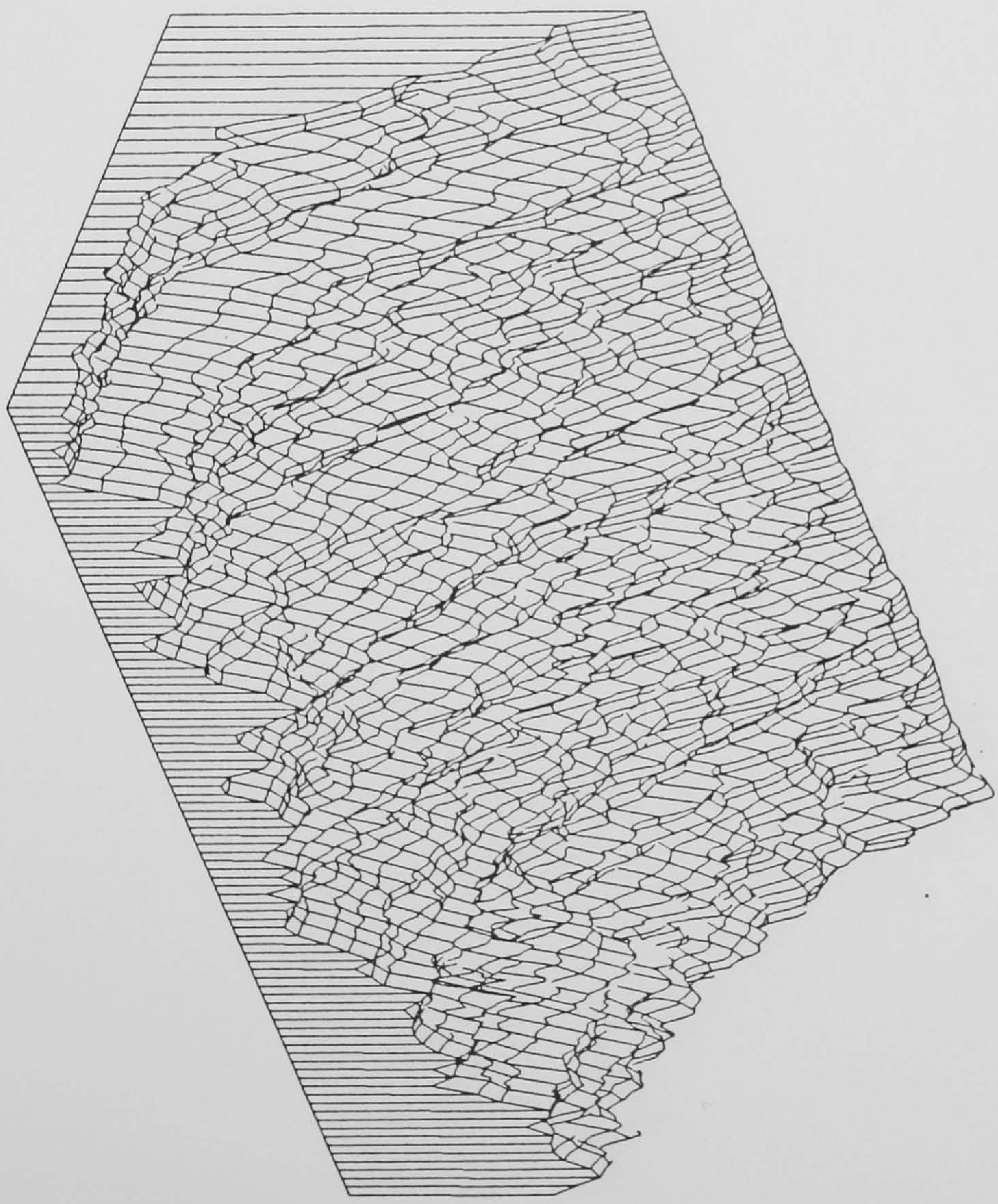


Fig. 62

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 2.1 SECONDS

PLOT NO. 2 DATE 02-18-87 TIME 11:54:36

AZIM = 135.0 ELEV = 25.0 DIST = 10000

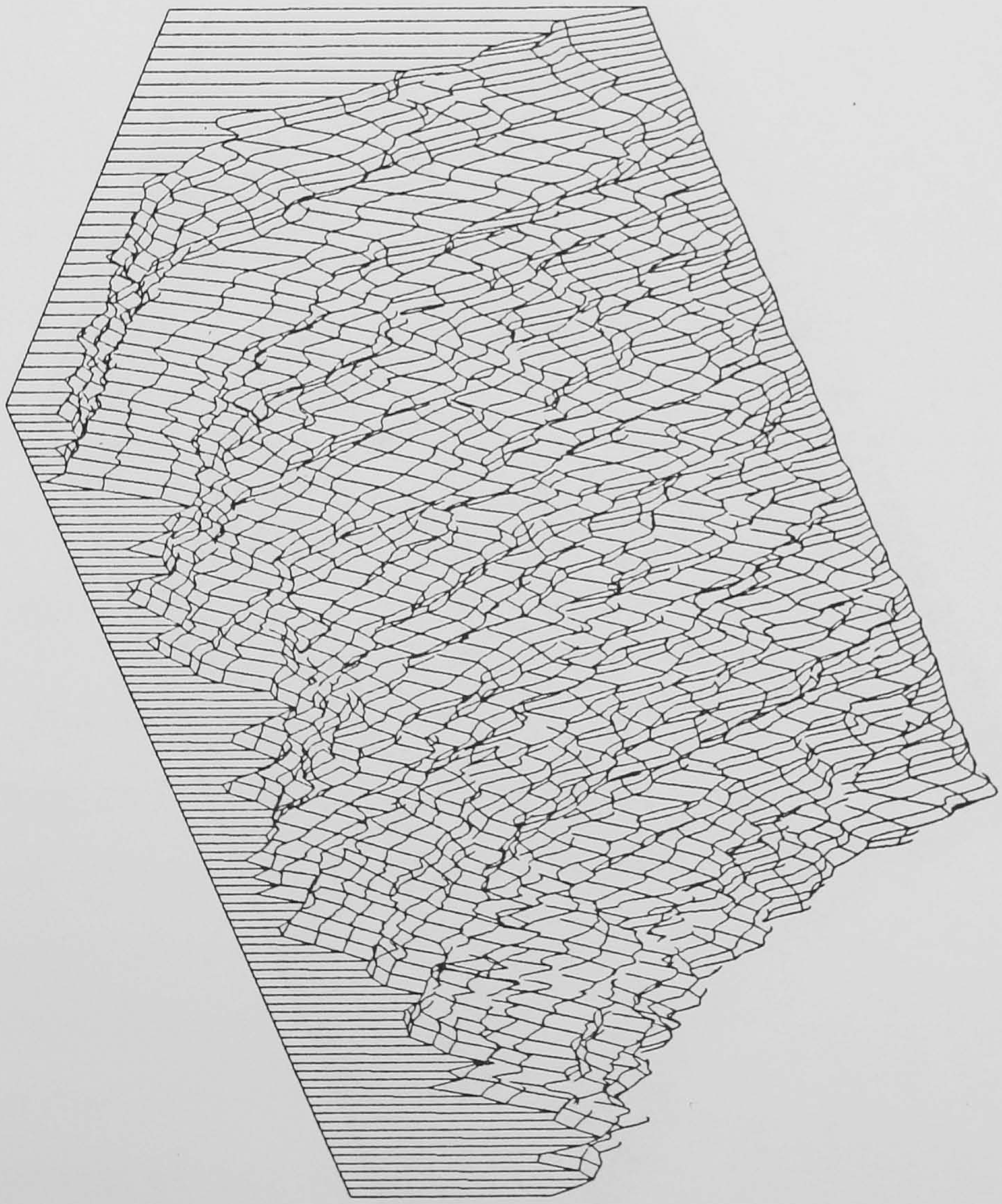


Fig. 63

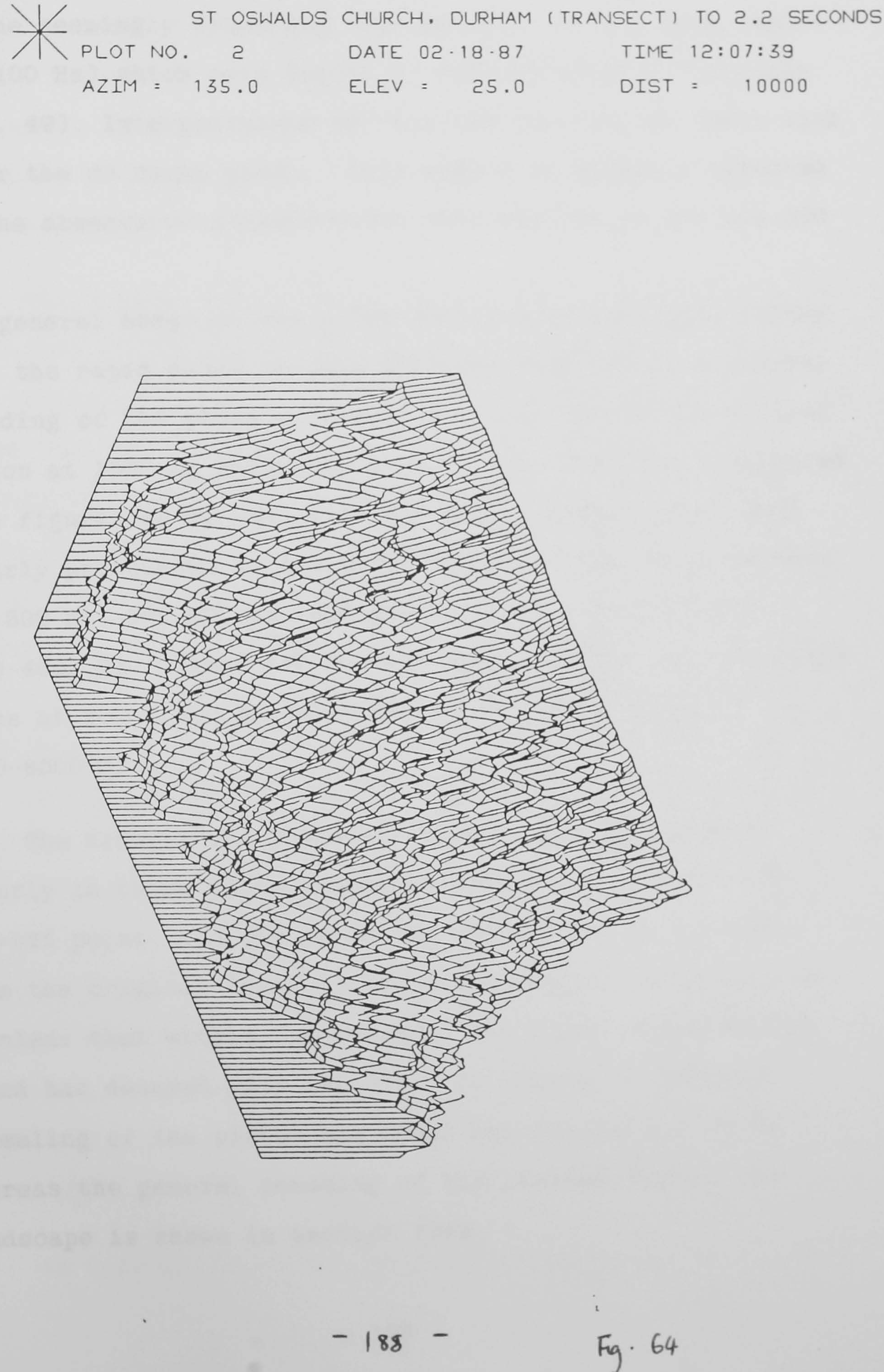

ST OSWALDS CHURCH, DURHAM (TRANSECT) TO 2.2 SECONDS
PLOT NO. 2
DATE 02-18-87
TIME 12:07:39
AZIM = 135.0
ELEV = 25.0
DIST = 10000

Fig. 64

Figure 48 shows the development of a subsidiary peak at about 500 Hz which decays in figure 49 and seems almost entirely absent in the subsequent plots in this series. Also evident is the seemingly lingering reverberation in the bass region (32-100 Hz) which only begins to develop after 0.7 seconds (fig. 49). Interpretation of this feature will be dealt with under the dB decay plots. This region is directly affected by the absence of filters which were applied at 100 and 200 Hz.

The general shape at the cross-sections of each plot (other than the rapid decay between 4000 and 8000 Hz) is a general rounding of the plots with a slight bias toward the central region at 1000 Hz (although this is only slightly pronounced (see figures 48 to 54), with specific resonant peaks most clearly pronounced in the early stages of the decay between 200-300 Hz, 500-600 Hz, 800-930 Hz, 1800-2200 Hz, and 3000-4000 Hz. There are corresponding troughs between these peaks at 300 - 500 Hz, 930-1800 Hz 2200-3000 Hz and 4000-8000 Hz.

The troughs and peaks are thrown into relief more clearly in those plots concerned with a variation in dB cut-off point. In figure 65 the cut-off point is -20dB from the original level of the sound source. Even here it is clear that within 0.4 seconds, the upper octave of the sound has decayed very rapidly. In figure 71 (the most revealing of the plots) the sound has decayed to -40dB, whereas the general rounding of the leading edge of the landscape is shown in another form.

The bass region in figure 66 shows the significant interference of traffic noise. The termination of this interference (figure 67) coincides with the application of the 75dB roll-off filter. The effects of background noise in the adjacent regions are are not visible until figures 71, 72 and 73; the lower frequencies are filtered out below 150 Hz, best shown in figure 71, by the interference in a wider bass region than figure 66.

The longer reverberation in the 200-300, 1800-2200 and 3000-4000 Hz bands are shown to best advantage in figure 71. The 'outcrop' between 800-930 Hz is shown to occur after the sound has decayed to -40 dB at about 1.4 seconds, the outcrop occuring at 1.7 seconds. During the recording of these sounds an aural record was made of peculiarities in the acoustic response of the building. Long reverberation times were audible between tenor Ab and mid E (207-311 Hz). 'bounces' in the reverberation time were noted at treble G# (784 Hz) and treble B (987 Hz) with slight fluctuations in the reverberation between 130 and 140 Hz, but these are difficult to interpret due to traffic interference. Confirmation of the audible 'bounce' in the reverberation (or surges of sound) is shown in figures 69 and 70 where the cut-off points are pin-pointed specifically at -37dB and -38dB. The reverberation 'bounce' at 800-930 Hz is clearly visible as are the fluctuations, or ridges, in the two prominent upper band regions. Figure 70, plotted to -38dB, shows this development most clearly.

An ordered decay was perceptible between 1174 Hz (d3)

ST OSWALDS, DURHAM TO 2.0 SECONDS WITH -20DB MIN (SM

PLOT NO. 2 DATE 02-20-87 TIME 14:23:16

AZIM = 135.0 ELEV = 25.0 DIST = 10000

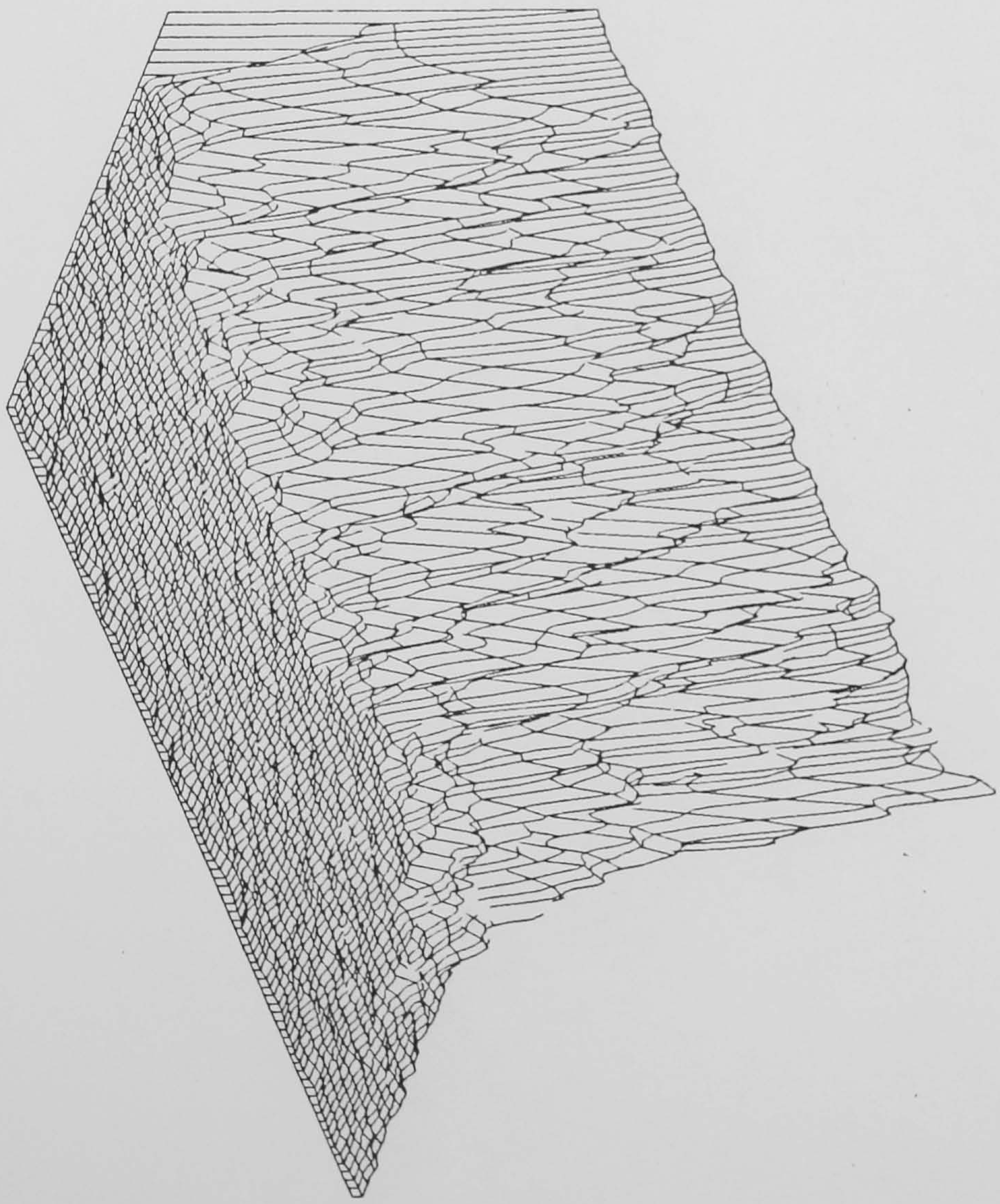


Fig. 65

ST OSWALDS, DURHAM TO 2.0 SECONDS WITH -25DB MINIMUM

PLOT NO. 2 DATE 02-20-87 TIME 13:55:06

AZIM = 135.0 ELEV = 25.0 DIST = 10000

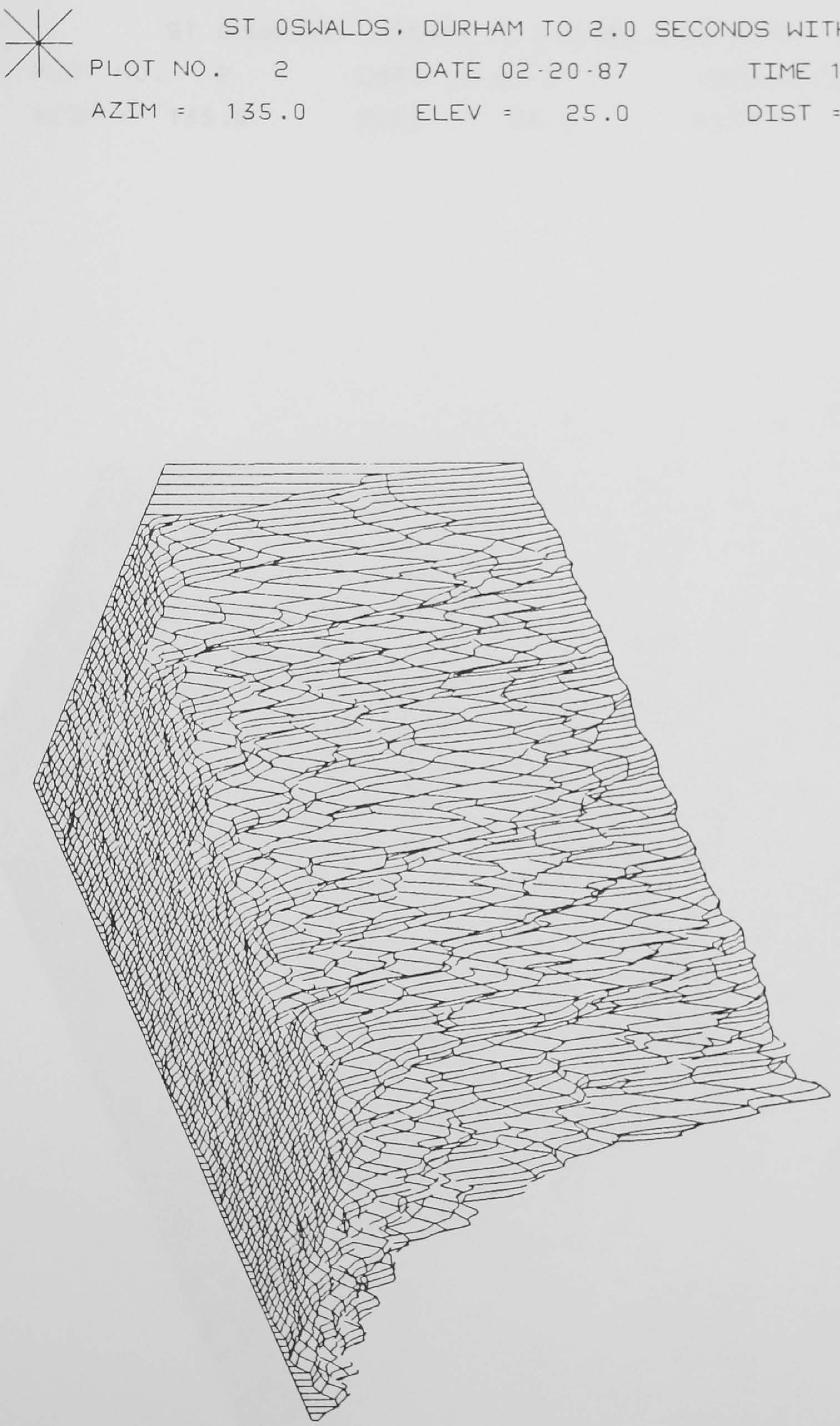


Fig. 66

ST OSWALDS, DURHAM TO 2.0 SECONDS WITH -30DB MINIMUM

PLOT NO. 2 DATE 02-20-87 TIME 13:41:57

AZIM = 135.0 ELEV = 25.0 DIST = 10000

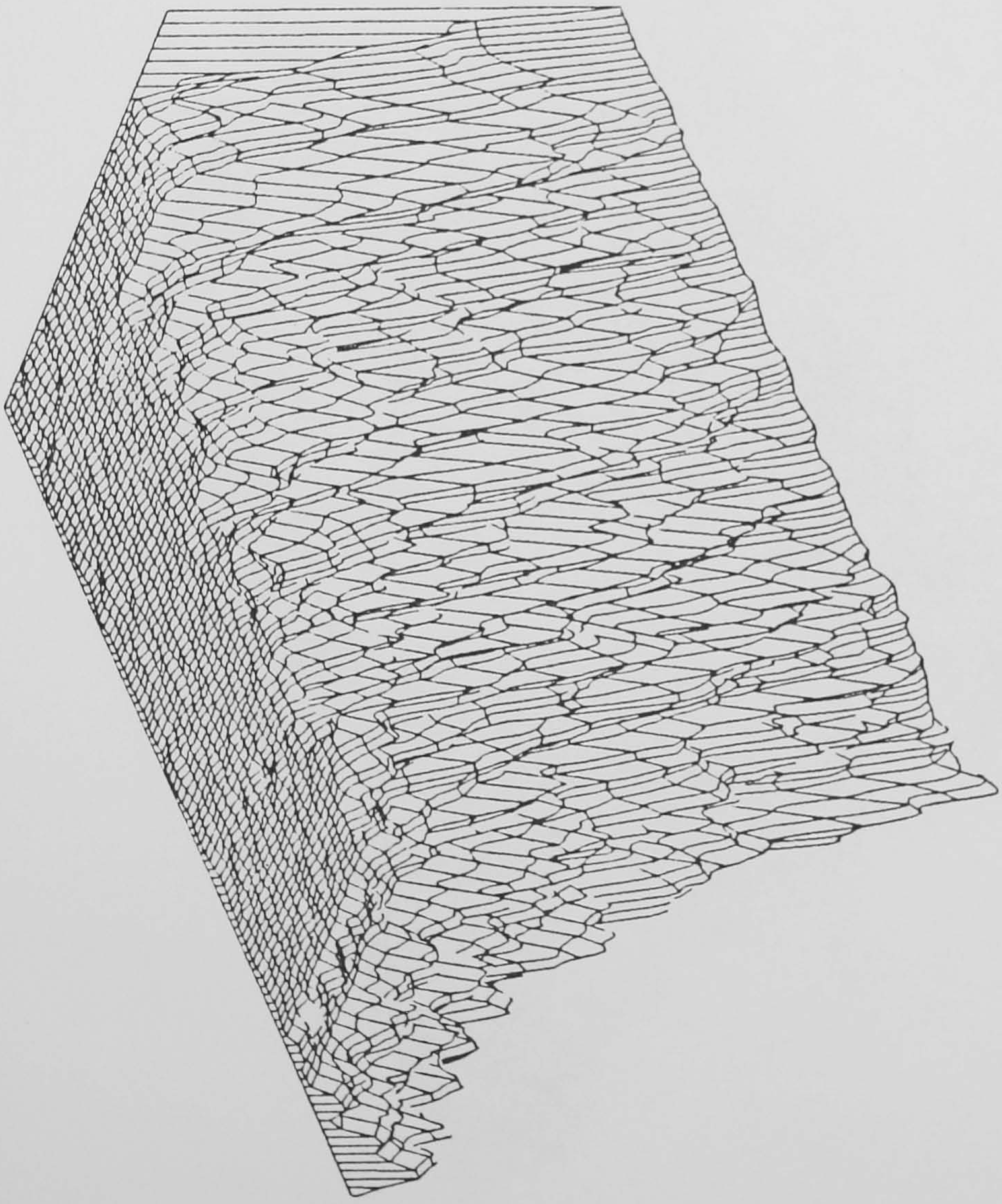


Fig. 67

ST OSWALDS, DURHAM TO 2.0 SECONDS WITH -35DB MINIMUM

PLOT NO. 2 DATE 02-20-87 TIME 13:28:47

AZIM = 135.0 ELEV = 25.0 DIST = 10000

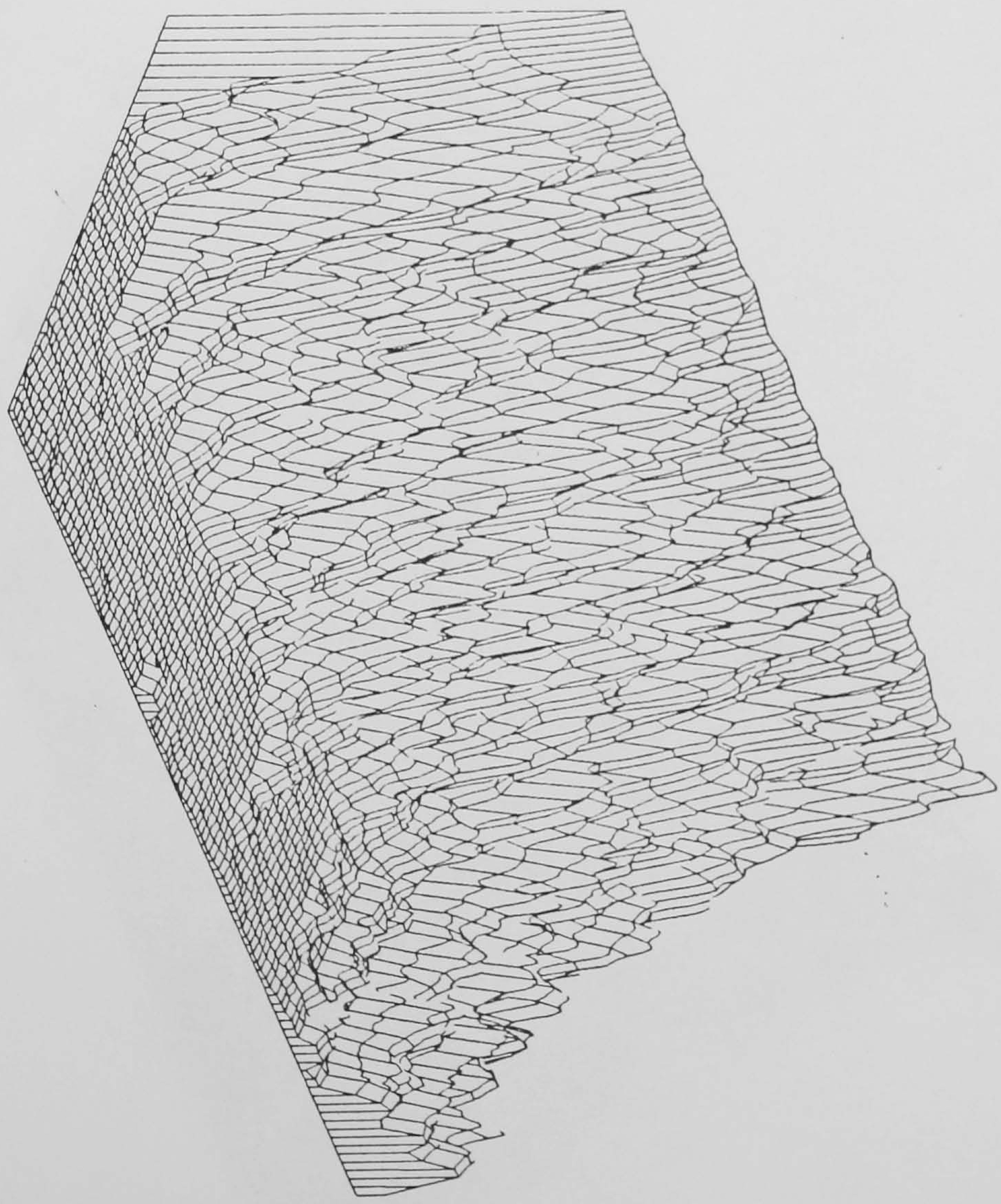


Fig. 68

ST OSWALDS CHURCH, DURHAM (TRANSECT) -37DB 2.2 SECS
PLOT NO. 2 DATE 06-02-87 TIME 11:34:40
AZIM = 135.0 ELEV = 25.0 DIST = 10000

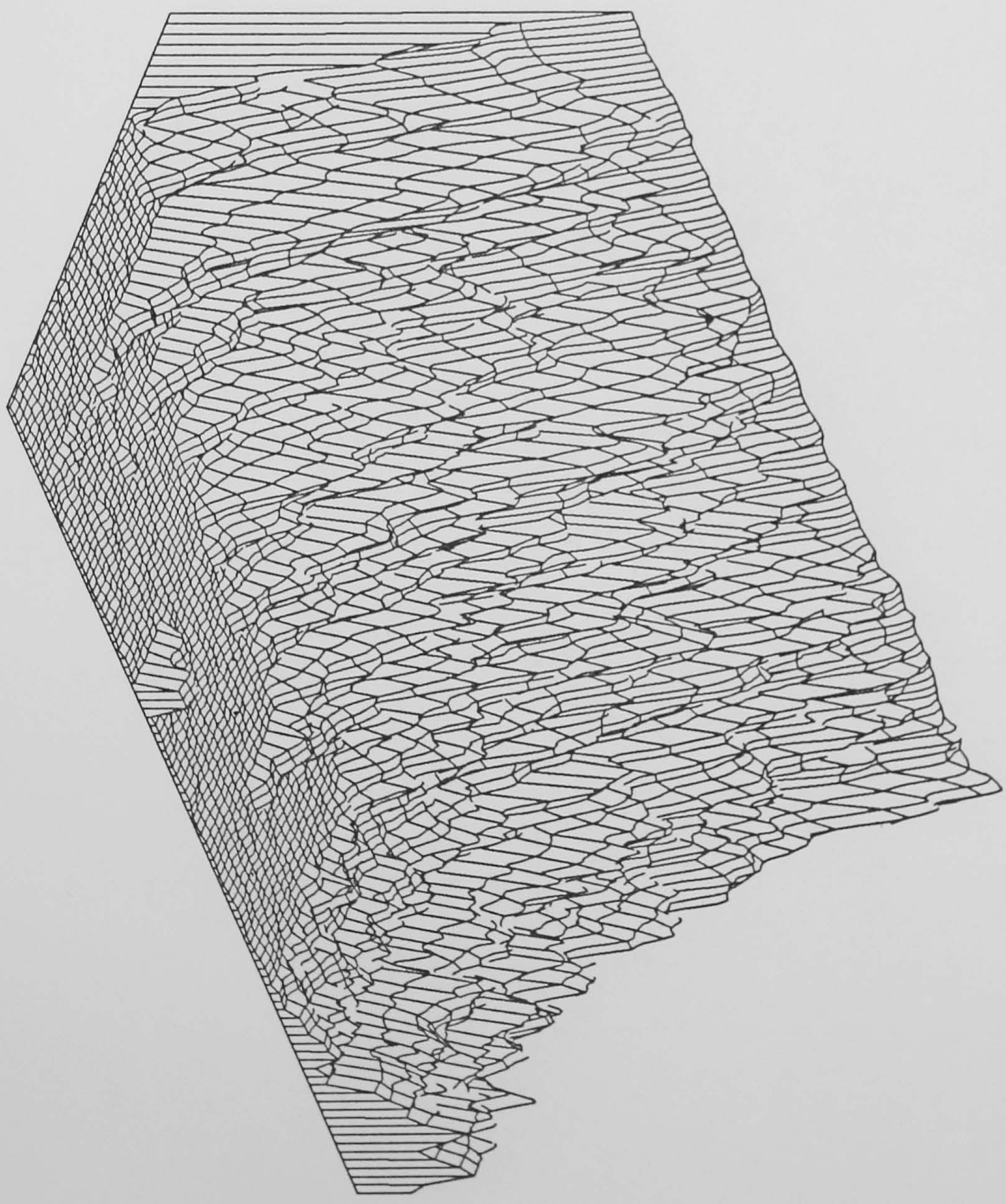


Fig. 69

ST OSWALDS CHURCH, DURHAM (TRANSECT) -38DB 2.2 SECS

PLOT NO. 2 DATE 06-02-87 TIME 11:24:31

AZIM = 135.0 ELEV = 25.0 DIST = 10000

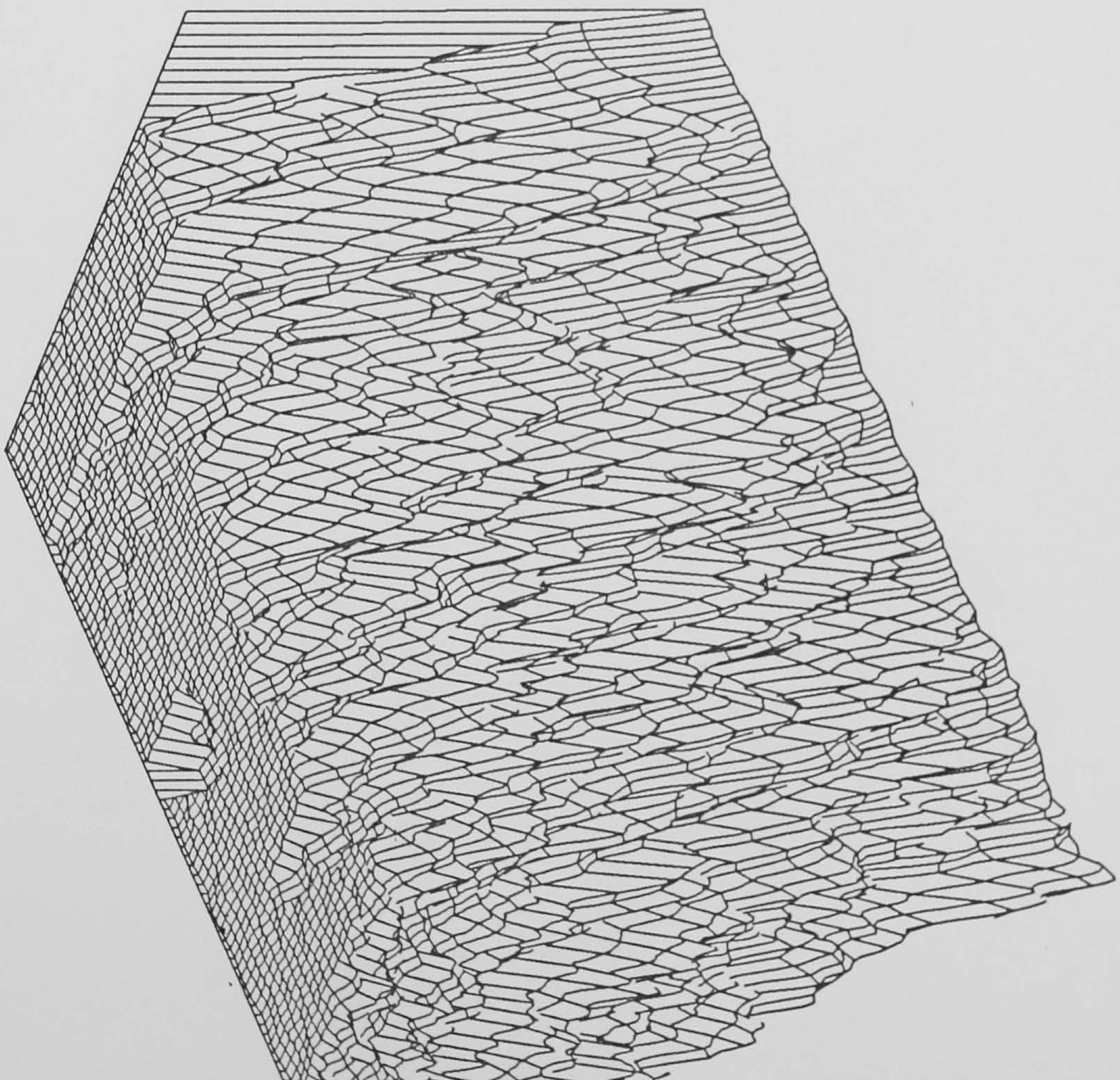


Fig. 70

ST OSWALDS, DURHAM TO 2.0 SECONDS WITH -40DB MINIMUM

PLOT NO. 2 DATE 02-20-87 TIME 13:13:23

AZIM = 135.0 ELEV = 25.0 DIST = 10000

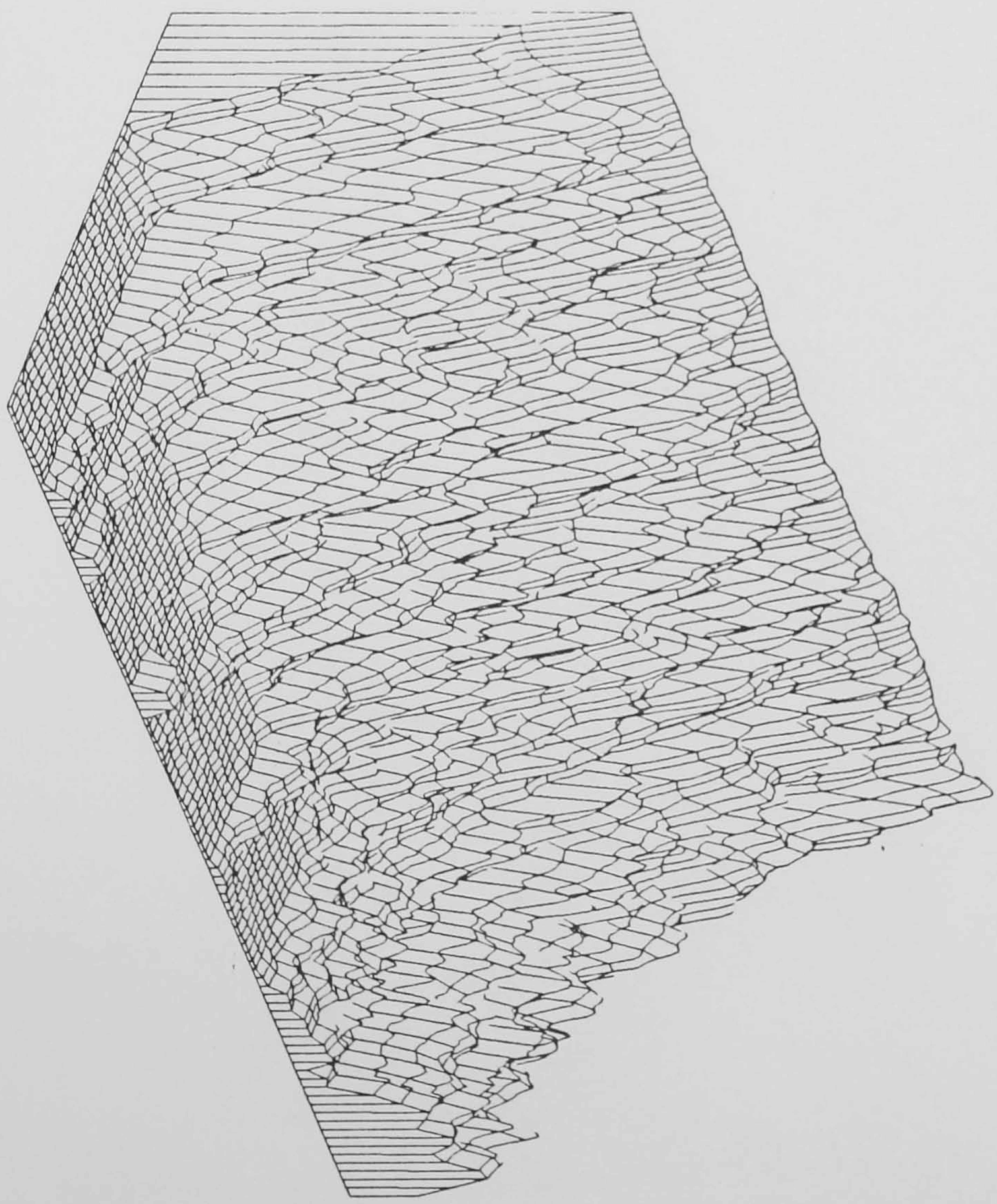


Fig. 71

ST OSWALDS, DURHAM TO 2.0 SECONDS WITH -45DB MINIMUM

PLOT NO. 2 DATE 02-20-87 TIME 12:54:41

AZIM = 135.0 ELEV = 25.0 DIST = 10000

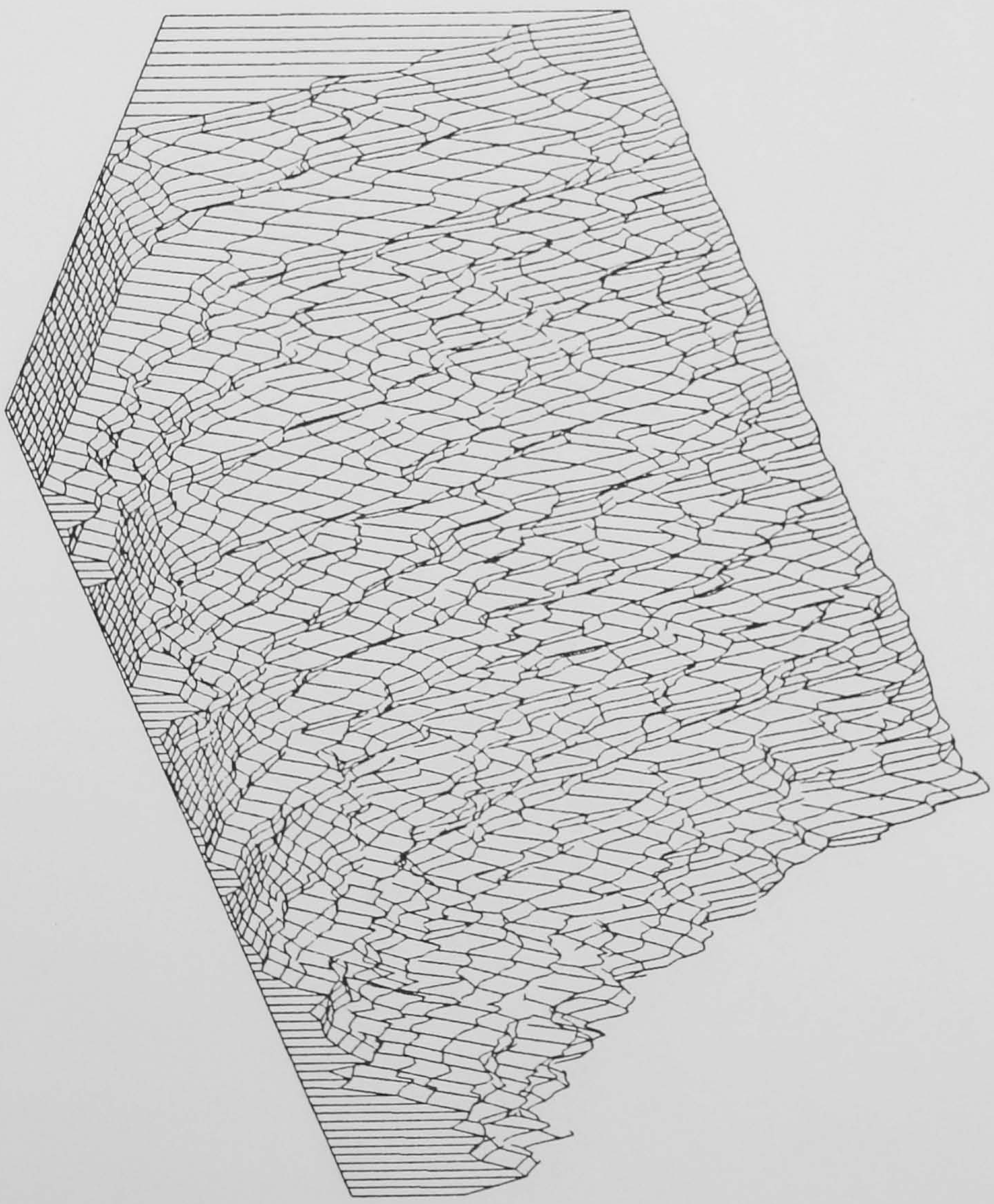


Fig. 72

ST OSWALDS, DURHAM TO 2.0 SECONDS WITH -50DB MINIMUM
PLOT NO. 2 DATE 02-20-87 TIME 12:29:37
AZIM = 135.0 ELEV = 25.0 DIST = 10000

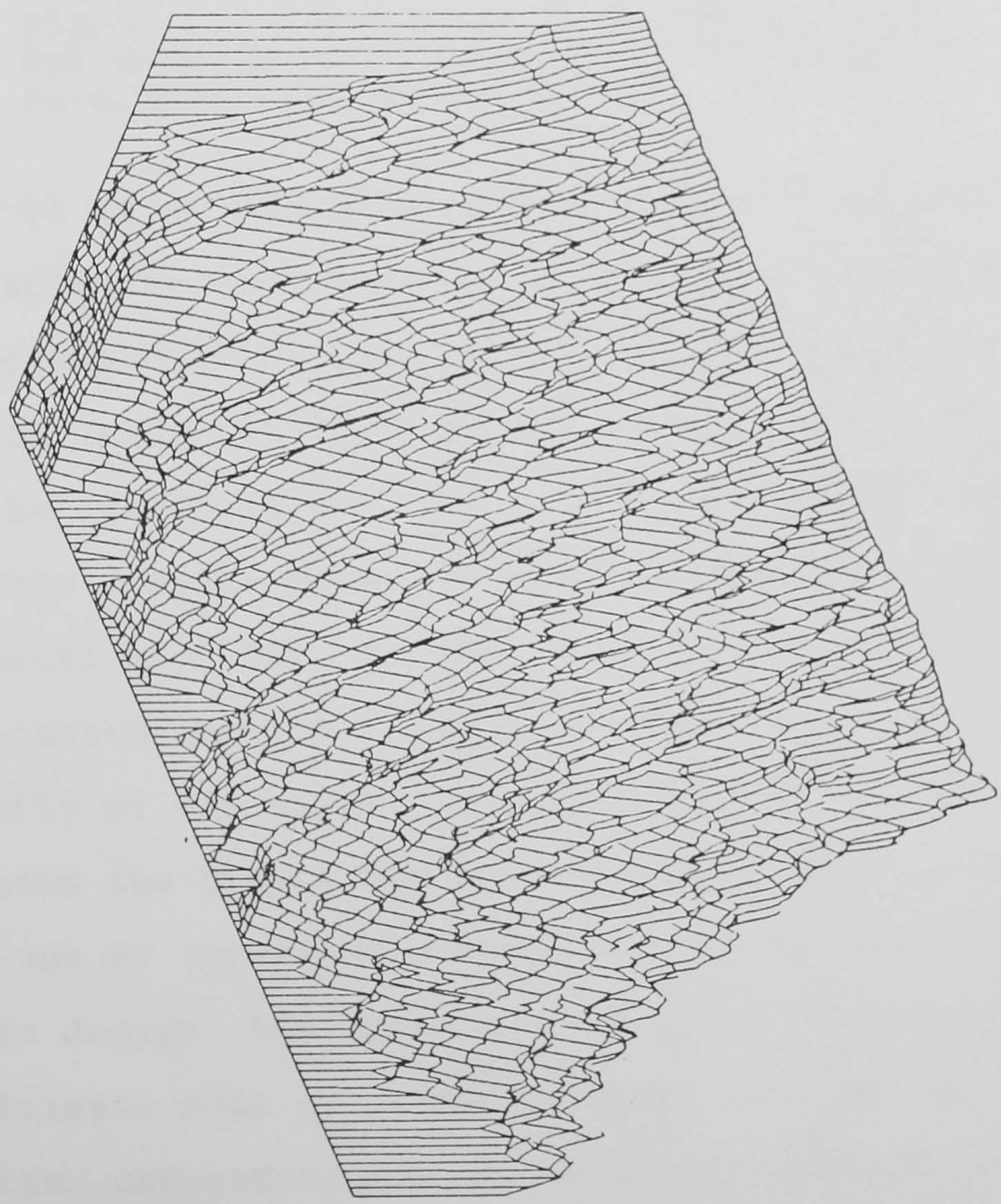


Fig. 73

and 1479 Hz (f#3) with a longer reverberation and fluctuations which become stronger as the frequencies approached c4 (2093 Hz). All these aural observations were borne out in the acoustic analysis. This is not surprising, as the aural training of a musician is of the essence, and the best organ-builders as musicians and craftsmen are sensitive to the sound requirements of a building. It is, therefore, no surprise when Williams[1] records the following concerning the Silbermann organ at Rötha

> 'The lowest general point in the Georgenkirche chorus - the point at which the pipes considered as a whole are narrowest - was exactly that favoured by the church's reverberation: middle c.'

It is no accident that an organ-builder sensitive to the acoustic conditions of a church should arrange the diameters of the pipes in such a way that the help that the church lends the sound is compensated for in the angustation of the diameters as a whole. The art of the organ-builder in this respect seems to have been diminished by the production of the 'factory organ' towards the end of the nineteenth-century - a process which not only demeaned the quality of the organs of that era, but one which also stunted the growth and development of individual builders. The use of logarithmic scales is not in itself a crime in organ design, but their short-sighted adaptation of a legitimate mode of pipe-production by organ-builders who neither understood the opportunities afforded by Sorge's proposals and Toepfer's implementation of them - or required any other understanding of them not concerned with labour reduction or the most convenient way of producing pipes on the work bench - shows how the dependence upon pre-calculated scales has destroyed the inquisitive nature of the organ-builder so common in previous centuries.

The process by which the best organ-builder derives his basic 8 foot principal scale seems to be based on unquantifiable experience culled from a basic knowledge of acoustics and on what is required musically for a particular location and its position in the tonal scheme of the organ. The decision to begin a scale on a diameter of x mm for 8 foot C seems to be the most arbitrary part of organ-building and yet paradoxically is one of the most certain decisions of the builder. The process of determining the starting diameter has been described as receiving its incarnation by 'dreaming in the pew', or that a particular builder 'feels it in his bones' that x mm is right for that building.

To attempt a logical process for the determination of that starting diameter would be to pour scorn and contempt on the very essence of the 'Art of Organ-Building'. The point of arrival at the determination of this measurement is the point of departure here. The power generated by a pipe is, first and foremost, a function of flue pressure but is also controlled by the pipe scale and the mouth dimensions relative to the diameter (or circumference). The organ-builder does not, however, choose a large scale and subsequently reduce the power of the pipe by reducing the flue pressure, but rather the choice of scale and desired output are chosen to match the building, as far as that is possible to discern aurally an acoustic environment. With

Theoretical pipe scale

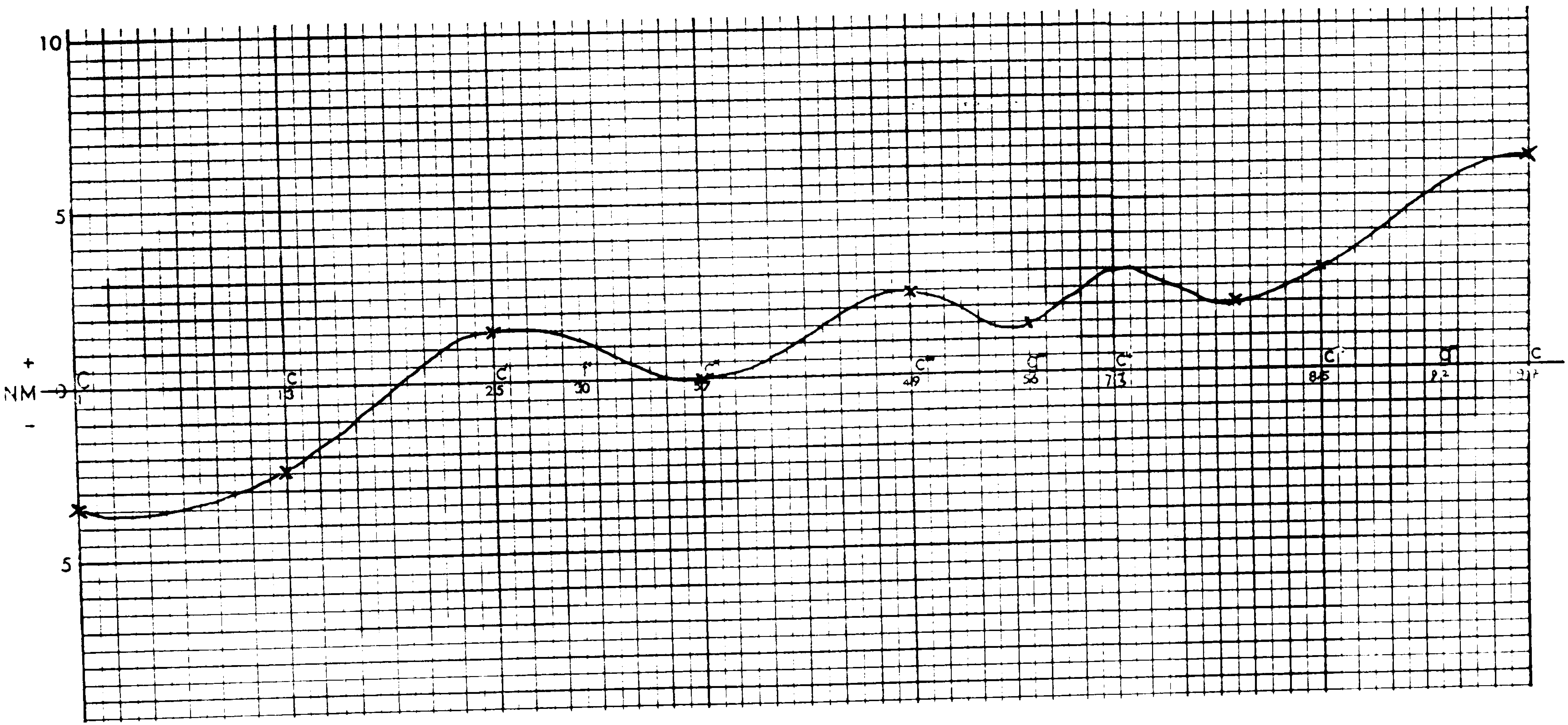


Fig 74

the help of an organ-builder, the chosen starting diameter was set at 138mm for C of the 8-foot Great Principal and 147mm for that of the Pedal Principal for the theoretical pipe-scales.

The first consideration for the eight octave range covered by the instrument was a basic scale for the entire range, on which musical considerations could later be imposed. A general description of the acoustic of the church seemed to be that the bass region was moderately unresponsive (in so far as that could be determined from traffic interference), a slight warming of the acoustic in the middle register (200-1000 Hz) and a little more in the upper-middle register (1000 - 4000 Hz) and a drastic absorption of frequencies in the 4000 - 8000 Hz range. This latter was likely to affect only the top octave of the 2 foot stops and indicates that mixture stops should avoid narrow scales to avoid shrillness and a top-heavy chorus. With these considerations borne in mind, a basic scale was formulated as below for the eight-octave range, (see figure 74).

This basic scale needed certain modifications before adaptation to a chorus structure, in that the 4-foot and 2-foot stops should not begin on a wider diameter than the 8-foot stop at that starting pitch. A common method of scaling is to make the 4-foot and 2-foot chorus stops slightly narrower than the 8-foot stop, and the 2-foot narrower than the 4-foot stop to introduce more harmonics and thus induce a brighter sound which might pall on the ear at lower pitches. There are, of course, no rules which govern a decision as to how much wider (or narrower) a stop should be in relation to the other members of its chorus, other than avoiding the extremes of scale which would take stops into another nomenclature. This is, perhaps, the organ-builder's *secretly kept art of scaling*.

From a study of the acoustic graphs, the subjective response of this writer was to widen the scale slightly throughout the rank as a whole, (whilst taking into account *regional* requirements in the building's acoustic) with a significant widening of the scale in the last octave of the 2-foot stop to compensate for the unkind acoustic in that frequency range. There are, naturally, many different possible versions of this theoretical pipe-scale which depend upon the designer's tonal outlook of the instrument taken as a whole. Common to musical requirements of the organ from all periods of musical history is the ability to execute counterpoint with clarity, particularly in the range from c to c1. To this end, the pipe-scale is slightly modified in that range to allow a wide band of sound in the output of the pipes, although the eight-octave scale produced such a configuration in the scale pattern in any case.

Whilst there may be responses to designing the present pipe-scale with an almost infinite number of musical and acoustic considerations taken into account, the temptation has been resisted to dwell on such differences and rather to consider the *method* required to obtain the measurements for the intervening semitones. Here we must consider the application of the computer program and ask the following questions:

1. is it desirable to employ an essentially *nineteenth*-century scaling method or an *eighteenth*-century one?

and

2. is the instrument to be tuned in any particular temperament and if so which one and how does that affect the diameter progression?

In order not to confuse the issue of temperament unduly, it has been applied only to the fixed-variable method and not to the logarithmic scaling method. This has been done because the method of Toepfer and Sorge did not involve the calculation of the scales according to temperament, (although Sorge advocated its use in the calculation of pipe-scales) and it has never been a historical reality. The method of Dom Bédos, on the other hand, is inherently based on temperament as it relies on the Pythagorean scale for the calculation of the ordinates on the base line of the scale-charts. The quotations on page 13 from both Sorge and Bédos show that the latter was not in favour of the calculation of scales according to temperament (he considered it a function of pipe *length*), whereas Sorge was, although he was an advocate of equal temperament.

The temperaments that have been incorporated into the computer program are those given by Padgham[2] and are listed in brief as follows:

Equal Temperament
Quarter Comma Mean Tone
Fifth Comma Mean Tone
Silbermann Sixth Comma Mean Tone
Werckmeister III (1691)

Kirnberger II (1779)
Modified Kirnberger II (1779)
Kirnberger III
Neidhardt I (1724)
Barnes proposed J.S.Bach Temperament
Kellner proposed J.S.Bach Temperament
18th Century English (Ord) Temperament
18th Century French *Temperament Ordinaire* I
18th Century French *Temperament Ordinaire* II
18th Century Italian
Vallotti (van Biezen)
Finchcocks (Byfield organ, 1766)
Oakes Park (England Organ, 1790)
Young (1800)
Royal Temperament (John Norman)
Pythagorean (Arnout van Zwolle, 15th Century)
Just Intonation

The intervals in cents (derived from equation 1.1) and the ratios given as decimals (rather than rational fractions) are listed in appendix D. The computer program in Fortran 77 is given in appendix C and reproduced as a schematic diagram in figures 75 and 76.

The eight-octave scale in figure 74 has been split into the main principal stops. Mixtures have been omitted here as their composition and disposition of breaks varies so widely. The same principle could be applied to such stops. The scales are given below and are plotted on figure 77.

Pedal	C	c	c1	f1
Principal 16	250.0	155.5	88	74
Octave 8	147.0	98.5	54.8	43.5

Great	C	c	c1	f#1	c2	f#2	c3	g3
Principal 8	138.0	86.0	58.5	-	32.5	-	21.3	15.2
Octave 4	78.5	52.0	29.4	-	19.2	14.2	11.5	8.0
Fifteenth 2	50.5	28.3	18.0	13.3	10.7	7.9	6.5	5.8

Using Fletcher's adaptation of the *quality factor* equation which is given as[3]

Scaling program: flow chart 1

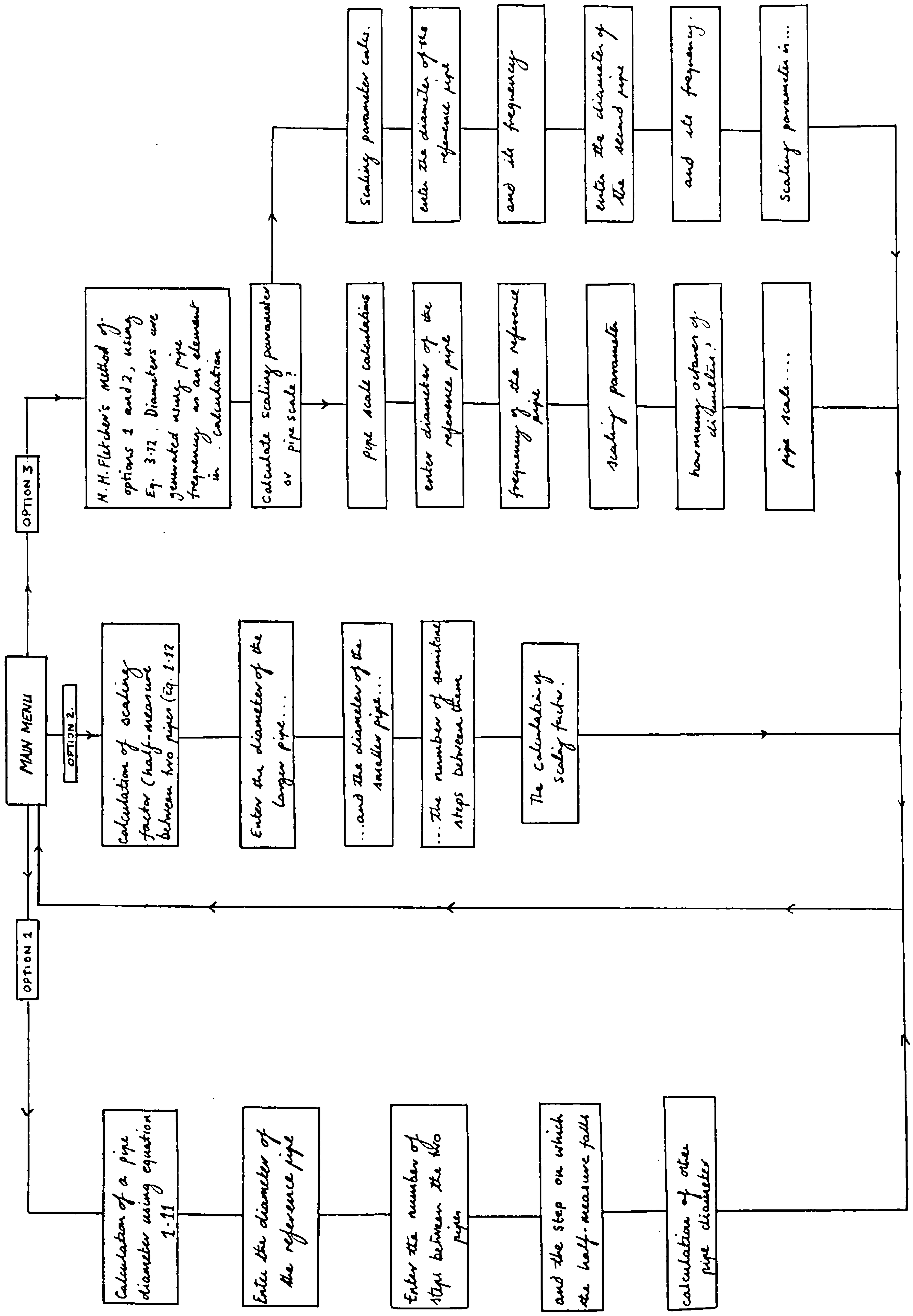


Fig. 75

Scaling program: flowchart 2

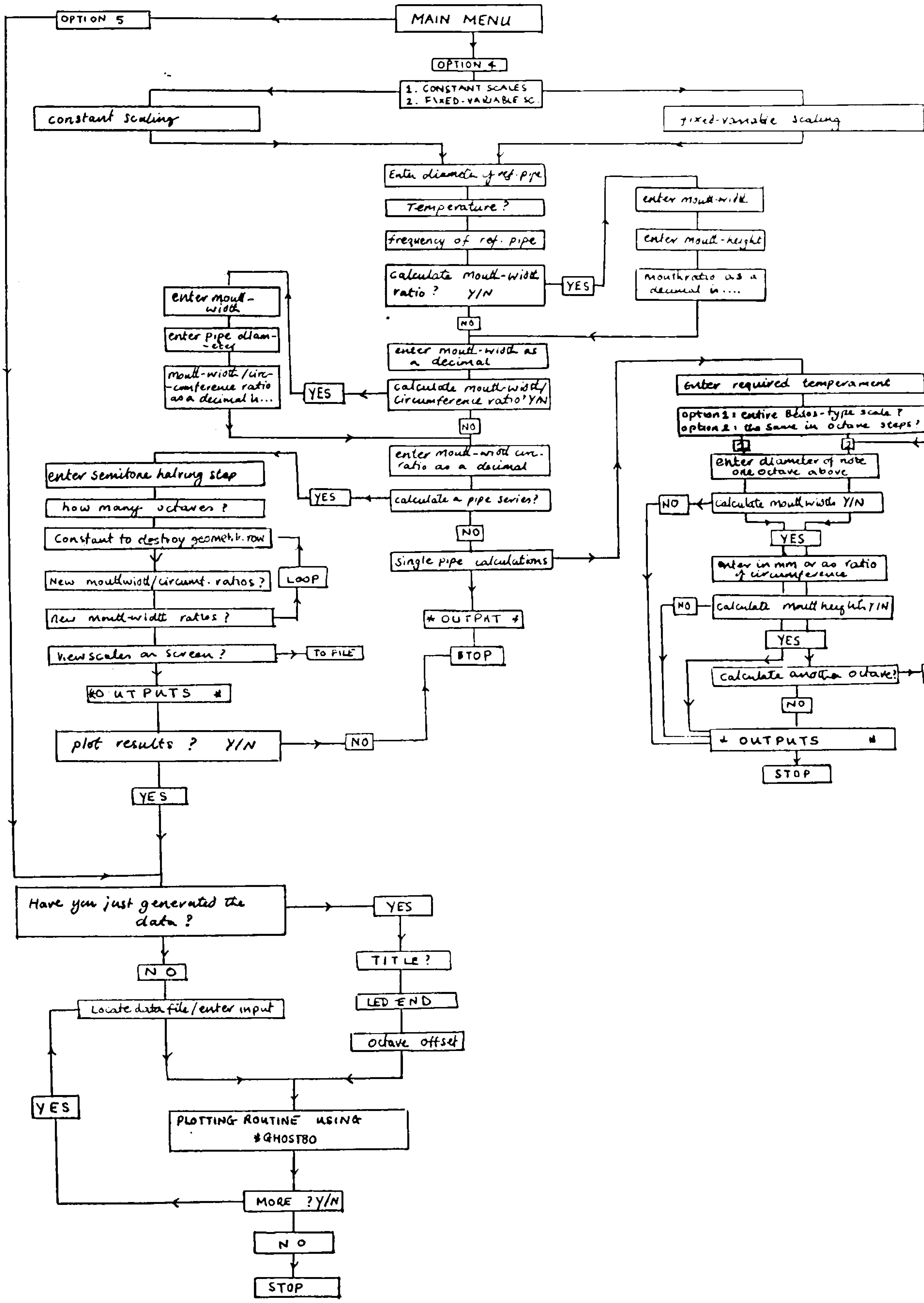
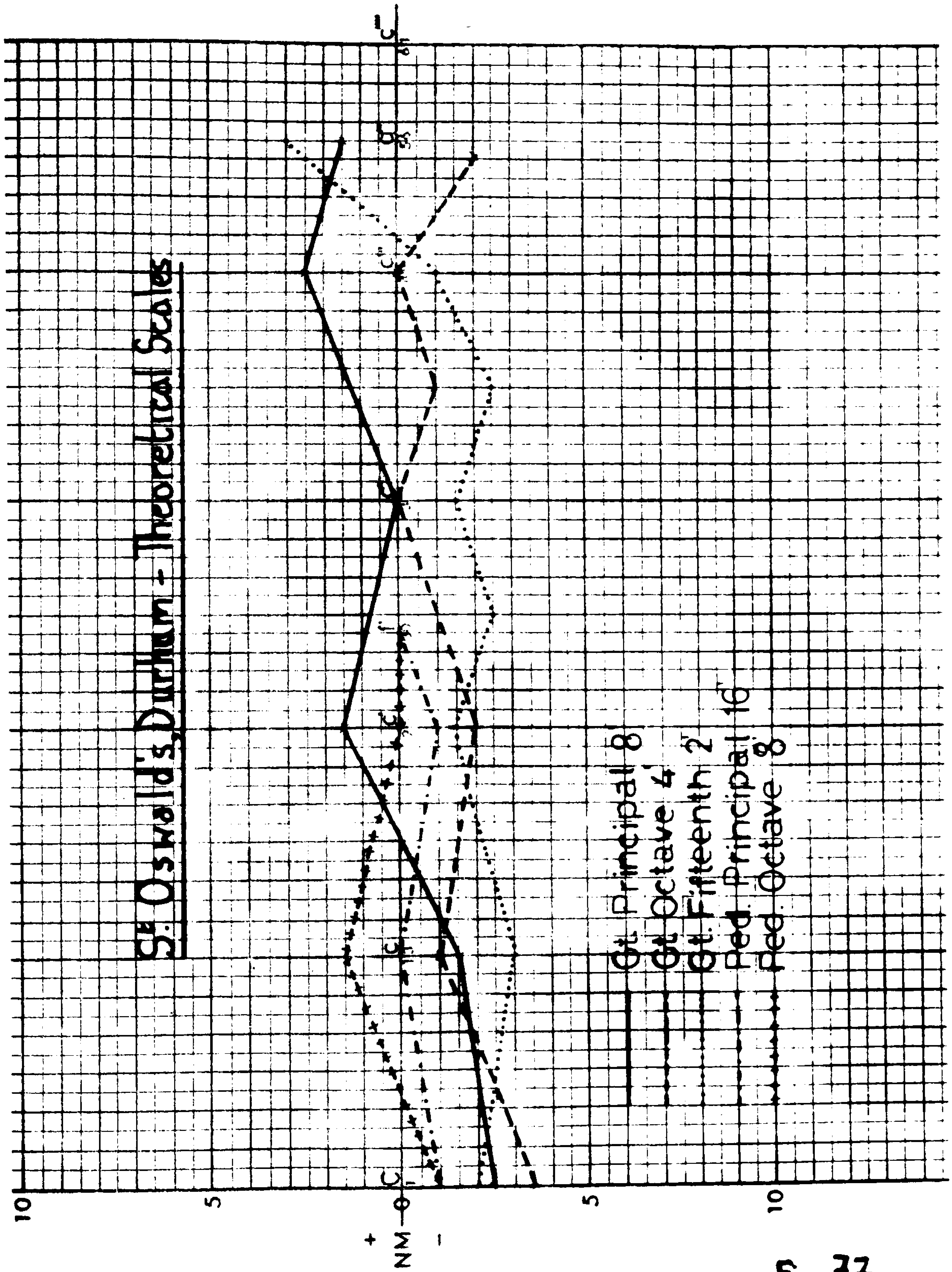


Fig. 76



St Oswald's Durham - Theoretical Scales
Gt. Principal 8'
Gt. Octave 4'
Gt. Fifteenth 2'
Ped. Principal 16'
Ped. Octave 8'
10
5
0
5
10
+
NM
-
C
c
c'
c''

Fig. 77

$$Q = (5 \times 10^{-5} vD^2L^{-1} + 1.4v^{-1/2}D^{-1})^{-1} \quad 4.1$$

where v is frequency
D is the diameter of a pipe of length L and
D and L are given in centimetres

seemingly arbitrary numbers (representing *quality* of sound) may be compared with the *quality factors* of adjacent pipes. If these numbers change their values (relative to each other) quickly, then this is an indication that the quality of sound generated by the rank will be changing as the rank ascends. In this way general changes in quality of tone may be represented by these *quality factors*. In equation 4.1 the first term represents radiation losses from the mouth and open end of the pipe, being the dominant term for wide pipes of high frequencies. The second term represents viscous and thermal losses to the pipe-walls, being dominant for narrow pipes at low frequencies. The equation has two components which differ in frequency dependence.

In applying the computer program to determine the diameters of the intervening semitones between the two c's, two sets of results are generated. The first set given below represents a compilation of several runs (a broken constant scale) using the Sorge/Toepfer logarithmic scaling method in which the scaling factor between any two c's alters as the scale ascends. The computed length figures indicate the lengths of metal sheet which would need to be cut; the circumference indicates their widths. For sake of safety and to avoid errors in calculation, the pipes would need to have a safety error margin of at most 5% of calculated pipe length added to each pipe. Then the pipes can be fine tuned and cut to the correct length if cone-tuning is employed. For pipes fitted with tuning-slides, the calculations would be adequate for cutting from sheet metal, as no major adjustment to the length of the pipe-body would need to be carried out. The scales are detailed in appendix F mainly in groups of an octave for each set of calculations.

The second 'run' applies the Bédos scaling method using Pythagorean temperament the scales being adjusted in each octave such that each octave unit represents a complete Bédos scale chart. Naturally the use of both pure constant scales and Bédos scales are prohibited by the fact that the scaling graph in figure 77 is of the free-variable type (*i.e.*, drawn by hand) and not the fixed-variable (Bédos) or the constant varieties (Sorge and Toepfer). The *quality factors* and Ingerslev and Frobenius's length formula are only applied in the calculation of constant scale units. The lengths of pipes in the Bédos method are dependent upon the frequency and hence on the position of the ordinate X_n on the base-line X1. As the pipes are hardly likely to be tuned to the uneven Pythagorean scale, this procedure is omitted in this method.

A close examination of these two scale varieties shows there is a subtle difference between the geometrical row of the constant method and the destruction of it using the Bédos method. In both cases the mouth-width is calculated as 1/4th of the circumference and the cut-up as 1/4th of the mouth-height. In the constant scale method it is possible

1 to alter the values of these important aspects of pipe construction at the input stage whereas the Bédos method is a little more uncompromising in this respect.

There are an almost infinite number of ways of obtaining the intervening diameters using the computer program, although demonstration of these methods is omitted here as the employment of constant and fixed-variable scale methods to derive the pipe-scales covers the major possibilities. The program may be used as an analytical tool to establish which scaling ratio is employed between two pipes or to calculate individual pipe diameters or pipe dimensions.

There are intended omissions. The first is that of the pipe-length formula used and devised by Cavaillé-Coll.

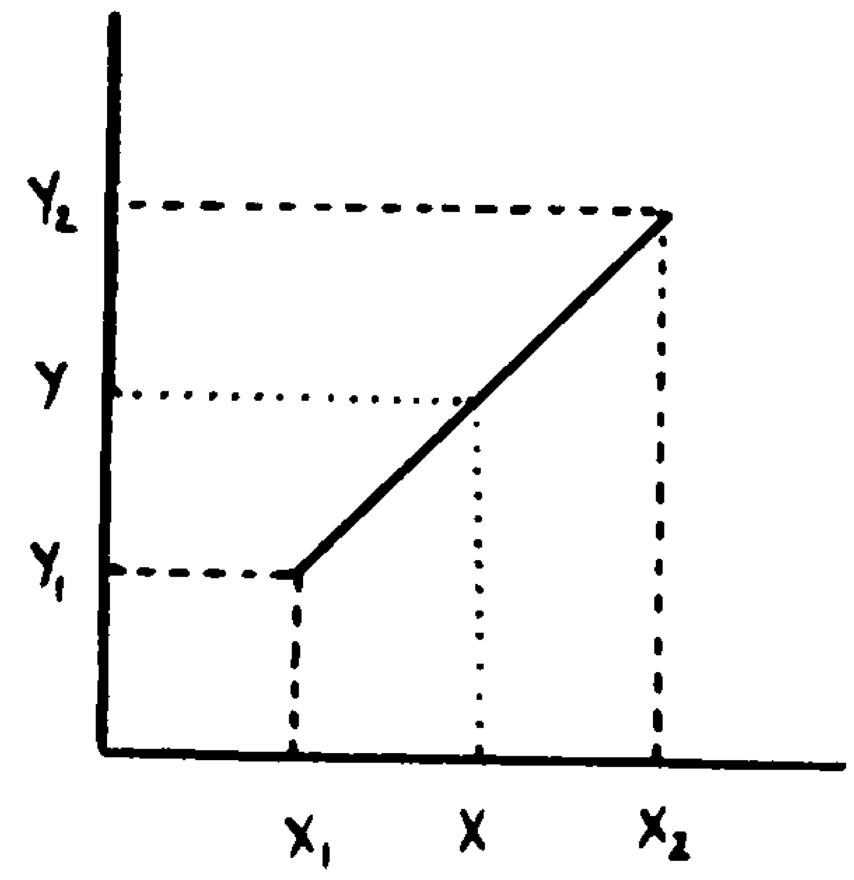
$$L = \frac{C}{V} - D \cdot \frac{5}{3} \qquad 4.2$$

where L is the pipe length
C is the speed of sound in metres per second
V is the pipe frequency and
D is the diameter in metres.

In comparison to Ingerslev and Frobenius' calculations, this formula is too inaccurate for consideration in the present work.

The other omission is a consideration of alternative methods of scaling. There are two such possibilities for determining the intervening diameters in a pipe scale where two (or more) diameters are known; the first has been explored by Dickson[4], although he probably did this by accident rather than by design. This is linear interpolation between two points. This requires the equation for the straight line joining the points 1 and 2 (see below). This equation may be written in the form given at equation 1.2 or as follows (for comparison with the second alternative method).

diameters



note numbers

Fig. 78

$$Y = \frac{X - X_2}{X_1 - X_2} Y_1 + \frac{X - X_1}{X_2 - X_1} Y_2 \qquad 4.3$$

The difficulty with this equation is that the diameters become uncomfortrably wide in the middle register in comparison with those which fall on a logarithmic curve. Presumably this kind of interpolation does yield acceptable results (at least for pipe-scales over short ranges) otherwise Dickson would not have advocated its use. No doubt part of its appeal is in the simplicity with which it may be drawn.

The second method is that of *controlled* parabolic interpolation. This is based on a parabolic curve passing through the points 1, 2 and 3 (see below). The points need not be equally spaced: the equation for the parabola may be

1 written as

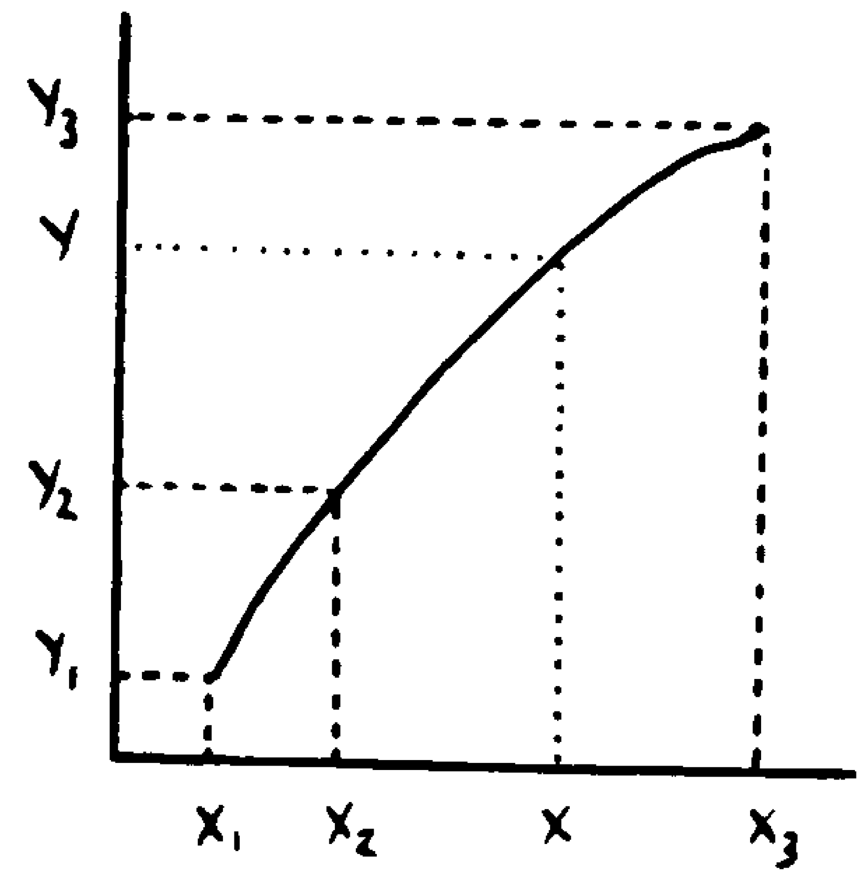


Fig. 79

$$Y = \frac{(X-X_2)(X-X_3)}{(X_1-X_2)(X_1-X_3)}Y_1 + \frac{(X-X_1)(X-X_3)}{(X_2-X_1)(X_2-X_3)}Y_2 + \frac{(X-X_1)(X-X_2)}{(X_3-X_1)(X_3-X_2)}Y_3$$

The point Y_2 might be a known diameter of note number X_2 falling on the curve between X_1, Y_1 and X_3, Y_3. From this the points X_n and Y_n could easily be determined. The points X_2, Y_2 could be chosen such that they fell at a point on the parabola on which the resulting diameters were of *reasonable* proportions. Hence the parabolic interpolation would need to be controlled. Such control might be found by using the *quality factor* equation so that the diameters must fall between limits beyond which the *quality factors* indicated that the sound-quality was changing too rapidly through the rank.

This thesis has attempted to compile various existing scaling methods and pipe-formulae from Bédos and Sorge to the present into one method of calculating open, cylindrical pipe-scales, and through such a study it is hoped that organ-builders will be able to scale principal or diapason stops with greater understanding, accuracy and with a sense of authenticity. There seems no point in constructing reproduction stop-knobs and console designs along authentic lines and providing a wealth of classical sonorities and chorus-structures with the c pipes designed according to what are considered to be 'classical scaling practices', when the intervening semitone steps are calculated according to a nineteenth-century formula (equations 1.10 and 1.11). Even the Rensch System provides logarithmic interpolation for the intevening semitones. Whilst the c measurements set the pipe out in a certain way (which is certainly not something to be critical of) they represent only a small fraction of the total pipes of the organ. There is much loose talk of 'Baroque wide-scale mutations' (to choose one example) which becomes meaningless in terms of the wider authenticity movement when the intervening notes are calculated in a nineteenth-century manner. Why are we used to endless discussions on playing-aids, pistons etc., when the kind of sound being sought is *still* not clearly defined?

There is an appreciable difference between the dimensions of a pipe-series constructed in the Bédos style and those following a logarithmic series. Although such pipes may be made to sound identical through variations in other aspects of voicing techniques (outlined in the introduction), manipulation of pipework forces a pipe into unnatural speech for its scale and construction. In this way the scale - the relationship of one pipe to another - determines the sound of the rank, something that the nineteenth-century organ builders worked against by using voicing techniques to obtain the required gradation of

1 sounds.

It is hoped that through this study the construction of pipe-scales will reach a new depth of understanding. bearing in mind that scaling is a relatively unexplored area of study.

Appendix A

Frobenius and Ingerslev calculate the end–correction, based on Rayleigh's work, as follows: in fig.37 is shown a tube with a closed and an open end. The tube is placed with its open end in a baffle of infinite extent. Let it be assumed that there is a very thin piston P with a mass $S.m_1$ at the opening of the pipe, where S is the area of the piston and m_1 the mass per unit area. The piston is vibrated harmonically at a frequency of f cycles per second. The air on the left of the piston (in the tube) and the air outside react upon the piston. The force due to the air in the tube is

$$-jSpc.cotkl_2.u$$

where

$S = \pi R^2$ (cross-sectional area of the tube)

k = wave number ($k = \frac{\omega}{c} = \frac{2\pi f}{c}$)

c = velocity of sound

l_2 = length of tube

u = velocity of the piston

p = mass per unit of volume

The force due to the air on the right side of the piston at low frequencies ($kR << 1$) is approximately given by

$$jS\omega\frac{8}{3\pi}pRu$$

There will be a resonance when the sum of these two forces and the mass force ($jS\omega m_1 u$) on the piston is 0 (i.e., when it is possible to move the piston without exercising any force

$$jSpc.cotkl_2.u + jS\omega\frac{8}{3\pi}pRu + jS\omega m_1 u = 0$$

$$-pcotkl_2 + (\frac{8R}{3\pi}p + m_1)k = 0 \qquad 1$$

1 shows that the air outside the tube has an effect upon the piston which may be interpreted as an increase in the mass of the piston of $\frac{8R}{3\pi}p$ per unit of area.

Actually there is no piston. The conditions 'without piston ' are given approximately as

$$-cotkl_2 + \frac{8R}{3\pi}k = 0 \qquad 2$$

when $m_1 = 0$

It was assumed that $k.R << 1$. When this is the case $cotkl_2 << 1$ and then

$$cotkl_2 = (2n+1)\frac{\pi}{2} - kl_2$$

where n is a positive integer. Hence

$$kl_2 + \frac{8R}{3\pi}k = (2n+1)\frac{\pi}{2}$$

and so

$$k(l_2 + \frac{8R}{3\pi}) = (2n+1)\frac{\pi}{2} \qquad 3$$

3 shows that the influence of the air outside the tube can be interpreted as an end correction l'_2 (fig.80) determined by

$$l'_2 = \frac{8R}{3\pi} = 0.85R$$

Rayleigh's more exact computation (Appendix A, Theory of Sound II) shows $l'_2 = 0.816R$

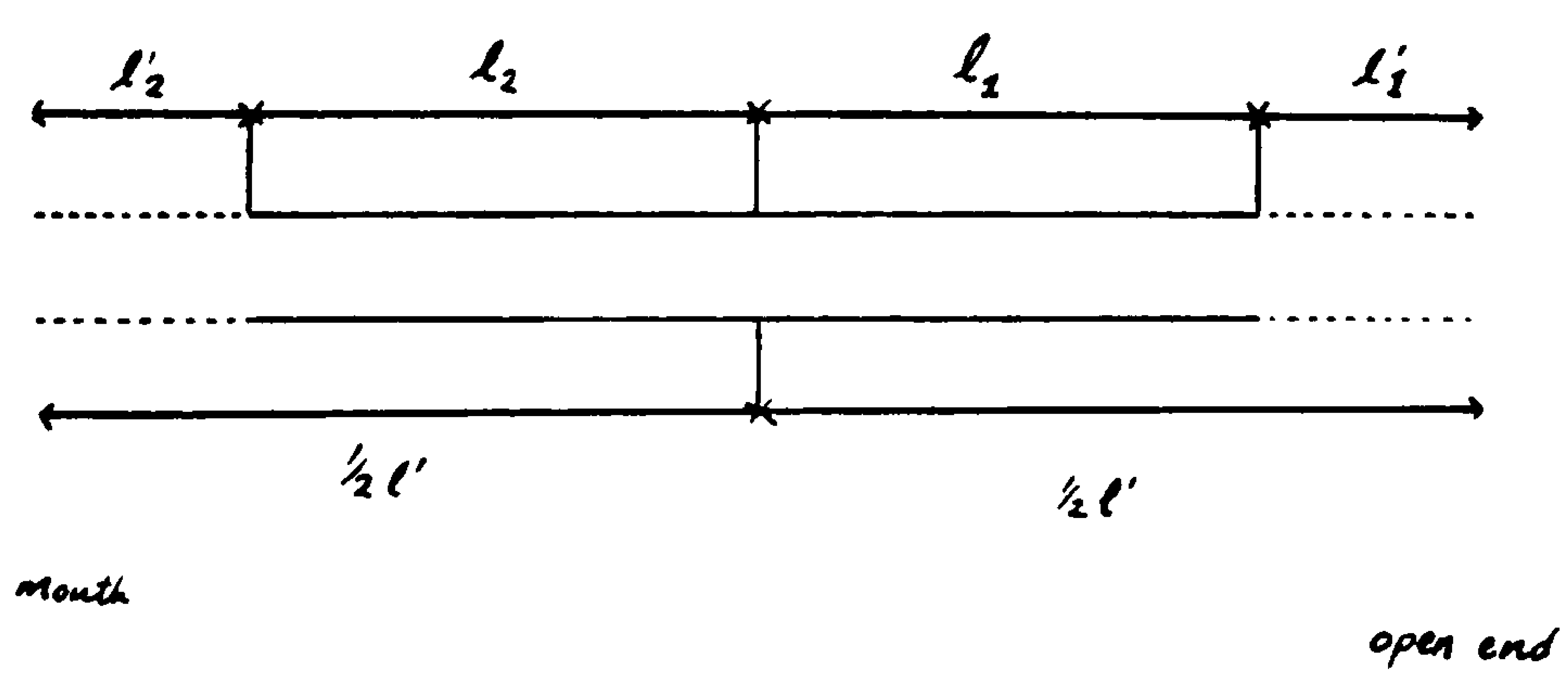


Fig. 80

Appendix B

Formula for

$$K(e) = \frac{2}{\pi}F(\epsilon)(1-e^2)^{\frac{1}{4}}$$

In the formula

$$F(\epsilon) = \int_0^{\frac{1}{2}\pi} \frac{d\theta}{\sqrt{(1-\epsilon^2 sin^2\theta)}} \qquad 1$$

-the 'elliptic integral of the first kind', ϵ is defined by

$$\epsilon^2 = 1 - \left(\frac{b}{a}\right)^2, \epsilon > 0 \qquad 2$$

There are a number of formulae for $F(\epsilon)$; the one that is most readily adapted to the calculations in which ϵ is closest to 1 is the following

Write

$$\epsilon'^2 = 1 - \epsilon^2 \qquad 3$$

and then define Σ by

$$2\Sigma = \frac{1-\sqrt{\epsilon'}}{1+\sqrt{\epsilon'}} \qquad 4$$

Having done that, define q by

$$q = \Sigma + 2\Sigma^5 + 15\Sigma^9 + 150\Sigma^{13} + ..., \qquad 5$$

where the infinite series in 5 converges rapidly if $|\Sigma| < \frac{1}{2}$. (The condition $|\Sigma| < \frac{1}{2}$ is satisfied if $0 < \epsilon < 1$, which is the case in these examples)

Now with the value of q given by 5,

$$F(\epsilon) = \frac{1}{2}\pi(1 + 2q + 2q^4 + 2q^9 + ...)^2 \qquad 6$$

and once again the series converges rapidly.

Substituting the formula 6 in the expression for $K(e)$ and noting that the $\frac{2}{\pi}$ cancels the $\frac{\pi}{2}$, we find:

$$K(\epsilon) = (1 + 2q + 2q^4 + 2q^9 + 2q^{16} + ...)^2(1-e^2)^{\frac{1}{4}} \qquad 7$$

which converges rapidly and is readily calculated.

Example $\frac{b}{a} = \frac{1}{4}$. Then

$$\epsilon^2 = 1 - \left(\frac{b}{a}\right)^2 = 1 - \frac{1}{16} = \frac{15}{16}$$

and

$$\epsilon'^2 = 1 = e^2 = \frac{1}{16}$$

so

$$\sqrt{e}' = \frac{1}{2}$$

and therefore

$$2\Sigma = \frac{1-\frac{1}{2}}{1+\frac{1}{2}} = \frac{\frac{1}{2}}{\frac{3}{2}} = \frac{1}{3}$$

$$i.e. \Sigma = \frac{1}{6}$$

Now

$$\Sigma^9 = 0.000000099$$

and may be neglected. So from 5

$$q = \frac{1}{6} + 2(\frac{1}{6})^5 = 0.1669239$$

Hence, from 7, if $\epsilon = \sqrt{\frac{15}{16}}$,

$$K(e) = (1 + 0.3338 + 0.0016)^2 (1 - \epsilon^2)^{\frac{1}{4}}$$

$$= 1.783293 \times 0.5$$

$$= 0.89$$

as required.

APPENDIX C

```
C ********************************************************************
C * PROGRAM DETERMINES THE DIMENSIONS OF ORGAN PIPES BY ANALYSIS &   *
C * GENERATION.  WILLIAM R MCVICKER  Fortran 77 Version   4.8.87     *
C *------------------------------------------------------------------*
C * MAIN: MAIN MENU                                                  *
C * SUBROUTINES: DIAMET, SCALEF, FLETCH MAKE ANALYSIS OF INDIVIDUAL  *
C * SCALES . SUBROUTINE MORAT CONVERTS MOUTH RATIOS TO DECIMALS, VIA *
C * ANALYSIS.                                                        *
C *                                                                  *
C *               Calculation of organ pipe diameters                *
C *                                                                  *
C *  1. using   log(D)= log(d) + (n/m)log(2)                         *
C *                                                                  *
C * F.E. Robinson Treatise on Practical Organ Building, London 1897. *
C *                                                                  *
C *  where D  Diameter of larger pipe                                *
C *        d  diameter of smaller pipe (no. n)                       *
C *        n  number of pipe (-ve for lower note!)                   *
C *        m  scaling factor                                         *
C *                     x                                            *
C * 2. using   D = d(V/v)                   N.H. Fletcher            *
C *                                          Acustica, 37, 1977      *
C *  where D  Diameter of pipe                                       *
C *        d  Diameter of ref pipe                                   *
C *        V  Frequency of pipe D                                    *
C *        v  Frequency of pipe d                                    *
C *        x  scaling parameter                                      *
C *                                                                  *
C *  this may be                                                     *
C *        0  Mediaeval pipe scales, all pipes same diam.            *
C *        1  diameter proportional to length                        *
C *        0.5 a rank with x-sectional area proportional to length   *
C *        0.75 standard modern scaling                              *
C *        0.83 tone should remain constant across compass with this *
C *------------------------------------------------------------------*
C * SUBROUTINE: ARROW                                                *
C * -----------------                                                *
C * This sub programme calculates complete scalings of open organ    *
C * pipes with end corrections & total computed length, using        *
C * Rayleigh, Frobenius & Ingerslev's formula for the end correction *
C * at the mouth.                                                    *
C * Options to calculate the ratio of MOUTH WIDTH : HEIGHT and that  *
C * of MOUTH WIDTH : CIRCUMFERENCE are also available.               *
C * Benade's Quality factor equation is employed to indicate the     *
C * general sound of the pipes.                                      *
C *------------------------------------------------------------------*
C * SUBROUTINE: GRAPH                                                *
C * -----------------                                                *
C * This routine plots scalings as deviations from the  NORM MESUR   *
C * Using *GHOST80                                                   *
C ********************************************************************
      CHARACTER REPLY
5     PRINT*
      PRINT*,'*********** ORGAN PIPE DIAMETER CALCULATOR **********'
      PRINT*
      PRINT*,'     All mesurements must be given in millimetres'
```

```
      PRINT*
      PRINT*,'You may calculate:'
      PRINT*
      PRINT*,'1: The Diameter of a single pipe'
      PRINT*,'2: The Scaling factor between two pipes (half-measure)'
      PRINT*,'3: The same calculations according to N.H. Fletcher'
      PRINT*,'4: Mouth dimensions'
      PRINT*,'5: Diameters, mouth dimensions and pipe lengths'
      PRINT*,'6: Normalmensur plotting routine'
      PRINT*
      PRINT'(1H&,A)','Choose 1,2,3,4,5,6  (or 0 to stop)'
      READ(5,*)I
      IF (I .EQ. 0) GOTO 10
      IF (I .EQ. 1) CALL DIAMET
      IF (I .EQ. 2) CALL SCALEF
      IF (I .EQ. 3) CALL FLETCH
      IF (I .EQ. 4) CALL MORAT
      IF (I .EQ. 5) CALL ARROW
      IF (I .EQ. 6) THEN
      CALL GRAPH
      GOTO 10
      ENDIF
      GOTO 5
10    PRINT*
      PRINT*,'          ******** End of session *******'
      PRINT*
      STOP
      END
C
C Subroutine: option 1, calculation of diameters.
C
      SUBROUTINE DIAMET
      PRINT*
      PRINT'(1H&,A)','What is the diameter of the reference pipe ? '
4     READ  (5,*) DREF
      PRINT*,'STEPS.  If the other, unknown pipe is larger, then'
      PRINT*,'enter the step value as a negative number.'
      PRINT'(1H&,A)','Now, enter the number of semitone steps, n   '
      READ  (5,*) STEPS
      PRINT'(1H&,A)','and the note on which the half measure falls (the
     :scaling factor, m   '
      READ  (5,*) SCFAC
C calculate d
      D=DREF / (2**(STEPS/SCFAC))
      WRITE (6,10) D
10    FORMAT(//1H ,'The other pipe has a diameter of ',F10.2/1H ,
     1'_____________________________________________'/)
      RETURN
      END
C
C  Subroutine: determination of the scaling factor.
C
      SUBROUTINE SCALEF
      PRINT*
      PRINT'(1H&,A)','What is the diameter of the larger pipe ? '
      READ  (5,*) DL
      PRINT'(1H&,A)','...and the diameter of the smaller pipe ? '
      READ  (5,*) DS
```

```
      PRINT'(1H&,A)','How many semitone steps between the two ? '
      READ  (5,*) STEPS
Calculate m now
      SF=(STEPS*LOG(2.0))/(LOG(DL)-LOG(DS))
      WRITE (6,10) SF
10    FORMAT(1H0,'The scaling factor then, is ',F10.2/1H ,
     1'______________________________________'/)
      RETURN
      END
C
C  Fletcher's calculations: using pipe frequency as an element
C
      SUBROUTINE FLETCH
      DIMENSION SCALE(108),DIAM(108)
      PRINT*
      PRINT*,'CALCULATIONS ACCORDING TO N.H.FLETCHER'
      PRINT*
      PRINT*,'You may calculate:'
      PRINT*,'1: Diameter of pipe'
      PRINT*,'2: Scaling Parameter'
      PRINT*
      PRINT'(1H&,A)','Choose 1,2 or 0 to stop'
      READ (5,*)I
      IF(I-1) 30,10,20
10    PRINT*
      PRINT'(1H&,A)','What is the diameter of the reference pipe ? '
      READ  (5,*) DREF
      CALL TABLE 3
      PRINT'(1H&,A)','enter the frequency of the reference pipe  '
      READ  (5,*) SCALE(1)
      PRINT*,'Using the following table'
      PRINT*,'SC PAR       STEP      RATIO'
      PRINT*,'1.091         11        1:2.1'
      PRINT*,'1.043         11.5      1:2.05'
      PRINT*,'1.000         12        1:2'
      PRINT*,'0.960         12.5      1:1.95'
      PRINT*,'0.923         13        1:1.19'
      PRINT*,'0.889         13.5      1:1.85'
      PRINT*,'0.857         14        1:1.8      (5:9)'
      PRINT*,'0.828         14.5      1:1.75     (4:7)'
      PRINT*,'0.800         15        1:1.73     (1:SQRT 3)'
      PRINT*,'0.774         15.5      1:1.714    (7:12)'
      PRINT*,'0.750         16        1:1.682    (1:4thRT 8)'
      PRINT*,'0.727         16.5      1:1.664    (3:5)'
      PRINT*,'0.706         17        1:1.633    (1:SQRT 2.66)'
      PRINT*,'0.686         17.5      1:1.6      (5:8)'
      PRINT*,'0.667         18        1:1.581    (1:SQRT 2.5)'
      PRINT*,'0.642         18.5      1:1.55'
      PRINT*,'0.632         19        1:1.5      (2:3)'
      PRINT*,'0.615         19.5      1:1.45'
      PRINT*,'0.615         20        1:1.4      (5:7)'
      PRINT*,'0.585         20.5      1:1.35'
      PRINT*,'0.571         21        1:1.3      (10:13)'
      PRINT'(1H&,A)','0.558         21.5      1:1.25     (4:5) Enter the S
     1caling Parameter'
      READ (5,*) SCPAR

      PRINT'(1H&,A)','For how many octaves?'
```

```
      READ (5,*) JOCT
      JNUMB=JOCT*12
      IF (JNUMB .GT. 108) THEN
        PRINT*
        PRINT*,'NO MORE THAN 10 OCTAVES - No output generated !'
        STOP
      ENDIF

Calculate constant semitone interval
      STONE=2.0**(1.0/12.0)

Calculate array of frequencies
      DO 13 I=2,JNUMB
      SCALE(I)=SCALE(I-1)*STONE
13    CONTINUE

Calculate the diameter
      DO 14 I=1,JNUMB
      DIAM(I)=DREF*((SCALE(1)/SCALE(I))**SCPAR)
14    CONTINUE

      CALL FTNCMD('ASSIGN 21=-FLETCH;')
      PRINT*,'  DIAMETER    FREQU.'
      WRITE (6,15) (DIAM(I),SCALE(I),I=1,JNUMB)
      WRITE (21,15) (DIAM(I),SCALE(I),I=1,JNUMB)
15    FORMAT (2(F9.2))
      RETURN

20    PRINT*
      PRINT'(1H&,A)','What is the diameter of the first pipe ? '
      READ (5,*) DIAM
      PRINT'(1H&,A)','   and the frequency of the first pipe ? '
      READ  (5,*) D1FREQ
      PRINT'(1H&,A)','What is the diameter of the reference pipe ? '
      READ  (5,*) DREF
      PRINT'(1H&,A)','   and the frequency of the reference pipe ? '
      READ  (5,*) DFREQ
Calculate the scaling parameter
C     SCPAR=-(LOG(DIAM)-LOG(DREF))/(LOG(D1FREQ)-LOG(DFREQ))
      WRITE (6,25) SCPAR
25    FORMAT(1H0,'The scaling parameter is ',F10.2/1H ,
     1'__________________________________'/)
30    RETURN
      END
C
C  Table for mouth ratio conversion
C
      SUBROUTINE TABLE1
      PRINT*
      PRINT*,'Using the following conversion table for ratios...'
      PRINT*
      PRINT*,'                     RATIO       DECIMAL'
      PRINT*,'                      1:2    =     2.0'
      PRINT*,'                      2:5    =     2.5'
      PRINT*,'                      1:3    =     3.0'
      PRINT*,'                      2:7    =     3.5'
      PRINT*,'                      1:4    =     4.0'
      PRINT*,'                      2:9    =     4.5'
```

```
      PRINT*,'                        1:5     =     5.0'
      PRINT*,'                        2:11    =     5.5'
      PRINT*,'                        1:6     =     6.0'
      PRINT*
      RETURN
      END
C
C  Table for halving ratios
C
      SUBROUTINE TABLE2
      PRINT*
      PRINT*,'Using the following table'
      PRINT*,'STEP      RATIO'
      PRINT*,'11       1:2.1'
      PRINT*,'11.5     1:2.05'
      PRINT*,'12       1:2'
      PRINT*,'12.5     1:1.95'
      PRINT*,'13       1:1.19'
      PRINT*,'13.5     1:1.85'
      PRINT*,'14       1:1.8   (5:9)'
      PRINT*,'14.5     1:1.75  (4:7)'
      PRINT*,'15       1:1.73  (1:SQRT 3)'
      PRINT*,'15.5     1:1.714 (7:12)'
      PRINT*,'16       1:1.682 (1:4thRT 8)  ***** NORMALMENSUR *****'
      PRINT*,'16.5     1:1.664 (3:5)'
      PRINT*,'17       1:1.633 (1:SQRT 2.66)'
      PRINT*,'17.5     1:1.6   (5:8)'
      PRINT*,'18       1:1.581 (1:SQRT 2.5)'
      PRINT*,'18.5     1:1.55'
      PRINT*,'19       1:1.5   (2:3)'
      PRINT*,'19.5     1:1.45'
      PRINT*,'20       1:1.4   (5:7)'
      PRINT*,'20.5     1:1.35'
      PRINT*,'21       1:1.3   (10:13)'
      RETURN
      END
C
C Simple table, called from BEDOS and ARROW
C
      SUBROUTINE MWCRC
      PRINT*
      PRINT*,'RATIO BETWEEN THE MOUTH-WIDTH : CIRCUMFERENCE'
      PRINT*
      PRINT*,'For a constant ratio between the two, the mouth (height :
     +width ratio'
      PRINT*,'should be the same value as for the mouth-width : circumfr
     +ence ratio'
      PRINT*
      PRINT*,'                        NACHTHORN         approx   6.5'
      PRINT*,'                        ITALIAN DIAPASON  approx   5.0'
      PRINT*,'                        NORMAL DIAPASON   approx   4.0'
      PRINT*,'                        VIOLIN DIAPASON   approx   3.0'
      PRINT*
      RETURN
      END
C
C Frequency table
C
```

```
      SUBROUTINE TABLE3
      PRINT*
      PRINT*,'Using the following table'
      PRINT*
      PRINT*,'              C PITCH      FREQUENCY'
      PRINT*,'                32          16.352079'
      PRINT*,'                16          32.703955'
      PRINT*,'                 8          65.407505'
      PRINT*,'                 4         130.814201'
      PRINT*,'                 2         261.626781'
      PRINT*,'                 1         523.250320'
      PRINT*,'                1/2       1046.494155'
      PRINT*,'                1/4       2092.975342'
      PRINT*,'                1/8       4185.924748'
      RETURN
      END
C
C BEDOS scaling method, called from within ARROW
C
      SUBROUTINE BEDOS
      REAL M,MW,MH,MMW,MMH,WIDIAM,WIDTH
      INTEGER JNUMB
      DIMENSION Y(108),KOUNT(108),ZNOTE(12),MW(108),MH(108)
      DIMENSION TEMPT(132),TEMPT1(120),RATIOS(108)
      DOUBLE PRECISION PIPL2(108),D(108),PI
      COMMON PIPL2,D,WIDIAM,WIDTH,JNUMB
      CHARACTER REPLY*1,REPLY1*1,BEDFIL*12
      PARAMETER(PI=3.14159265358979323846)
      DATA TEMPT /1.000000,1.059464,1.122462,1.189207,1.259921,1.334840,
     +1.414213,1.498306,1.587400,1.681792,1.781797,1.887748,1.000000,
     +1.044908,1.118036,1.196282,1.249997,1.337487,1.397542,1.495350,
     +1.562502,1.671855,1.788861,1.869184,1.000000,1.049462,1.119426,
     +1.194053,1.253106,1.336653,1.402759,1.496274,1.570283,1.674968,
     +1.786631,1.875001,1.000000,1.051118,1.119929,1.193239,1.254243,
     +1.336351,1.404664,1.496612,1.573125,1.676109,1.785826,1.877114,
     +1.000000,1.053501,1.117403,1.185188,1.252831,1.326416,1.404664,
     +1.494926,1.580246,1.670436,1.777778,1.879240,1.000000,1.053494,
     +1.125000,1.185182,1.249997,1.333329,1.406247,1.500004,1.580246,
     +1.677049,1.777778,1.875001,1.000000,1.054712,1.122462,1.185188,
     +1.249997,1.333329,1.404664,1.498306,1.580246,1.675160,1.777778,
     +1.872890,1.000000,1.053501,1.118036,1.185188,1.249997,1.333329,
     +1.406247,1.495350,1.580246,1.671855,1.777778,1.875001,1.000000,
     +1.055883,1.119929,1.186524,1.254243,1.333329,1.407840,1.496612,
     +1.583819,1.676109,1.777778,1.879240,1.000000,1.055883,1.119929,
     +1.187861,1.254243,1.336351,1.407840,1.496612,1.583819,1.676109,
     +1.781797,1.881370,1.000000,1.053494,1.118921,1.185188,1.258503,
     +1.333329,1.404664,1.495937,1.580246,1.673836,1.777778,1.877971/
      DATA TEMPT1 /1.000000,1.051118,1.118036,1.182173,1.249997,1.332206
     +,1.403074,
     +1.495350,1.574898,1.671855,1.774771,1.872879,1.000000,1.052838,
     +1.118637,1.184436,1.251348,1.337124,1.403780,1.495748,1.579252,
     +1.673207,1.779739,1.871700,1.000000,1.051125,1.119929,1.183847,
     +1.254243,1.333329,1.404664,1.496620,1.576682,1.676109,1.777778,
     +1.877125,1.000000,1.049935,1.117403,1.181177,1.248590,1.331828,
     +1.401495,1.494926,1.573125,1.670436,1.773767,1.870771,1.000000,
     +1.055883,1.119929,1.187861,1.254243,1.336351,1.407840,1.496612,
     +1.583819,1.676109,1.781797,1.877125,1.000000,1.057629,1.122462,
     +1.199555,1.259921,1.341797,1.413397,1.499172,1.584652,1.681792,
```

```
     +1.796264,1.886658,1.000000,1.052752,1.121166,1.189207,1.256288,
     +1.333299,1.410950,1.500039,1.580082,1.681792,1.783856,1.879045,
     +1.000000,1.055883,1.119929,1.187861,1.254243,1.336351,1.404664,
     +1.496612,1.580246,1.676109,1.777778,1.877114,1.000000,1.053494,
     +1.125000,1.185188,1.265625,1.333329,1.404664,1.500004,1.580246,
     +1.687495,1.777778,1.898442,1.000000,1.066666,1.125000,1.199999,
     +1.249997,1.333329,1.406247,1.500004,1.600003,1.666668,1.777778,
     +1.874969/
C
C
      PRINT*
      PRINT*,'          +++++++++ TEMPERAMENT +++++++++'
      PRINT*
      PRINT*,' 1. Equal Temperament           13. Approx. 18thC French'
      PRINT*,' 2. Quarter Comma Mean Tone          Ordinaire version II'
      PRINT*,' 3. Fifth Comma Mean Tone       14. French 18thC Version II'
      PRINT*,' 4. Silbermann                  15. 18thC Italian'
      PRINT*,' 5. Werckmeister III            16. Vallotti'
      PRINT*,' 6. Kirnberger II               17. Finchcocks (Byfield 1796
     :)'
      PRINT*,' 7. Modified Kirnberger II      18. Oakes Park (England & So
     :n,1790)'
      PRINT*,' 7. Kirnberger III              19. Royal (John Norman)'
      PRINT*,' 9. Neidhart I (1724)           20. Pythagorean (Bedos chart
     :s)'
      PRINT*,'10. Barnes proposed J.S.Bach  21. Just intonation'
      PRINT*,'11. Kellner proposed J.S.Bach'
      PRINT*,'12. 18th C. English  Ord'
      PRINT*
      PRINT*
      PRINT*,'To calculate scales according to a particular temperament'
      PRINT*,'Enter the required number. For the original scale of Dom'
      PRINT*,'Bedos, enter Pythagorean.'
      PRINT*
      PRINT'(1H&,A)','Enter a number'
      READ*,TEMP

      IF (TEMP .LT. 12) THEN
        I=((TEMP-1)*12)+1
        K=1
        DO 1 J=I,I+11
        ZNOTE(K)=TEMPT(J)
        K=K+1
1       CONTINUE
      ELSE
        N=((TEMP-12)*12)+1
        K=1
        DO 3 J=N,N+11
        ZNOTE(K)=TEMPT1(J)
        K=K+1
3       CONTINUE
      ENDIF
C Loop to fill array ZNOTE with selected temperament array of 13
      DO 5 J=1,108
      JL=J
4     IF (JL .LE. 12) THEN
         RATIOS(J)=ZNOTE(JL)
      ELSE
```

```
         JL=JL-12
         GOTO 4
      ENDIF
5     CONTINUE
C-----------------------------------------------------------------------
      PRINT*
      PRINT*,'Do you wish to calculate'
      PRINT*,'1. the entire scale by entering the diameter one octave ab
     +ove, or'
      PRINT*,'2. a scale calculated octave by octave?'
      PRINT*
      PRINT'(1H&,A)','Enter 1 or 2     '
      READ*,I
      IF (I .EQ. 1) GOTO 100
      IF (I .EQ. 2) GOTO 10
C-----------------------------------------------------------------------
10    K=1
      L=13
C L= diameter entered in ARROW read as PIPL2(1)
      Y(K)=D(1)
C X13 is the length of the chart calculated in ARROW
      X13=PIPL2(1)
C Y=MX + C , WHEN X=0, Y=C (ie, it's serial number = 0)
      C=Y(K)
      PRINT*
      PRINT'(1H&,A)','Enter the diameter one octave above (mm)'
      READ*,Y(L)
C C has been determined, now calculate M from Y(L)
      M=(Y(L)-C)/X13
C-----------------------------------------------------------------------
13    DO 15 I=K,L-1
      Y(I)=((M*2.0)*(1-(1/RATIOS(I)))*X13)+C
15    CONTINUE
C-----------------------------------------------------------------------
      PRINT*
      PRINT'(1H&,A)','Do you want to calculate mouth-widths? Y/N'
      READ'(A1)',REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
         PRINT*,'Do you wish to enter the mouth width as'
         PRINT*,'1. a ratio of pipe  circumference or '
         PRINT*,'2. in millimeteres?'
         PRINT*
         PRINT'(1H&,A)','Enter 1 or 2      '
         READ*,I

            IF (I .EQ. 1) THEN
               PRINT*
               MW(K)=(2*PI*(Y(K)/2))/WIDIAM
               WRITE(6,20) MW(K), WIDIAM
20             FORMAT('The mouth width of the larger pipe is',F9.3,'mm',/
     +,'and its ratio to the circumference of',F9.3)
               PRINT*
               PRINT*,'                    SMALLER PIPE'
               PRINT*,'Do you want to calculate the mouth-width : circumf
     +erence'
               PRINT'(1H&,A)','ratio from known data? (Y/N)'
               READ'(A1)',REPLY
               IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y'))THEN
```

```
                CALL MWRAT
                GOTO 25
             ELSE
                CALL MWCRC
             ENDIF
25              PRINT*
                PRINT'(1H&,A)','Enter the ratio as a decimal for the sm
     +aller pipe'
                READ (5,*) SIZE2
                MW(L)=(2*PI*((Y(L)/2)))/SIZE2
                GOTO 30

           ELSE

             PRINT*
             PRINT'(1H&,A)','Enter the mouth-width of the larger pipe'
             READ*,MW(K)
             PRINT*
             PRINT'(1H&,A)','Enter the mouth-width of the smaller pipe'
             READ*,MW(L)
             GOTO 30
           ENDIF

30       CMW=MW(K)
         MMW=(MW(L)-CMW)/X13

         DO 35 I=K,L
         IF (I .EQ. 13) THEN
           RATIOS(I)=2.0
         ENDIF
         MW(I)=((MMW*2.0)*(1-(1/RATIOS(I)))*X13)+CMW
35       CONTINUE

      ELSE
         GOTO 60
      ENDIF

      PRINT*
      PRINT'(1H&,A)','Do you want to calculate mouth-heights? Y/N'
      READ'(A1)',REPLY

      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
         PRINT*
         PRINT*,'Do you wish to enter the mouth height as'
         PRINT*,'1. a ratio of mouth width, or '
         PRINT*,'2. in millimeteres?'
         PRINT*
         PRINT'(1H&,A)','Enter 1 or 2      '
         READ*,J

         IF (J .EQ. 1) THEN
              PRINT*
              MH(K)=MW(K)/WIDTH
              WRITE(6,40) MH(K), WIDIAM
40            FORMAT('The mouth height of the larger pipe is',F9.3,'mm',
     +/,'and its ratio to the mouth width is',F9.3)
              PRINT*
              PRINT*,'                SMALLER PIPE'
```

```
         PRINT'(1H&,A)','Do you want to calculate the mouth ratio fro
     +m known data?  (Y/N)'
         READ'(A1)',REPLY

         IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
            CALL MORAT
         ELSE
            CALL TABLE1
         ENDIF

         PRINT*
         PRINT'(1H&,A)','Enter the mouth-ratio as a decimal for the s
     +maller pipe'
         READ (5,*) CUTUP2
         MH(L)=MW(L)/CUTUP2
         GOTO 45

      ELSE

         PRINT*
         PRINT'(1H&,A)','Enter the mouth-height of the larger pipe'
         READ*,MH(K)
         PRINT*
         PRINT'(1H&,A)','Enter the mouth-height of the smaller pipe'
         READ*,MH(L)
         GOTO 45

      ENDIF

45    CMH=MH(K)
      MMH=(MH(L)-CMH)/X13
      DO 50 I=K,L
      MH(I)=((MMH*2.0)*(1-(1/RATIOS(I)))*X13)+CMH
50    CONTINUE

   ELSE
      GOTO 60
   ENDIF


   PRINT*
   PRINT'(1H&,A)','Calculate another octave? Y/N'
   READ'(A1)',REPLY1
   IF ((REPLY1 .EQ. 'Y') .OR. (REPLY1 .EQ. 'y')) THEN
      K=K+12
      L=L+12
C Re-evaluate X13 & C , but not M which is constant
      X13=PIPL2(1)/2
      C=Y(K)
      PRINT*
      PRINT'(1H&,A)','Enter the diameter one octave above (mm)'
      READ*,Y(L)
      GOTO 13
   ELSEIF ((REPLY1 .EQ. 'N') .OR. (REPLY1 .EQ. 'n')) THEN
      PRINT*
      PRINT*,'Enter the name of file for output'
      PRINT*,'Pressing [RETURN] will mean the filename -BEDOS'
      PRINT*,'is assumed.'
```

```
         PRINT'(1H&,A)','DATAFILE:  '
         READ '(A12)',BEDFIL
         IF (BEDFIL .EQ. '             ') BEDFIL= '-BEDOS'
         CALL FTNCMD ('ASSIGN 30='// BEDFIL //';')
         CALL EMPTYF (30)
         REWIND (30)
         WRITE (30,55) (Y(I),MW(I),MH(I),I=1,L-1)
         PRINT*,'   DIAMETER       MOUTH WIDTH       MOUTH HEIGHT'
         WRITE (5,55) (Y(I),MW(I),MH(I),I=1,L-1)
55       FORMAT (3(5X,F9.3))
         GOTO 999
      ENDIF

60    WRITE (5,65) (Y(I),I=1,L-1)
65    FORMAT (F9.3)
      GOTO 999
C---------------------------------------------------------------------
100   Y(1)=D(1)
      XL=PIPL2(1)
      C=Y(1)
      K13=13

      PRINT*
      PRINT'(1H&,A)','and the diameter of the note one octave above mm'
      READ*,Y(K13)
      PRINT*
      PRINT'(1H&,A)','For how many notes do you want a scale?  '
      READ*,KTOP
      IF (K13 .GE. 96) THEN
         PRINT*,'ERROR MESSAGE **** NO MORE THAN 108 NOTES !!'
         GOTO 999
      ENDIF

      M=(Y(K13)-C)/(XL/2)

      K=0
      DO 150 KL=1,KTOP,12
      N=KL+12

      DO 125 I=KL,N
      Y(I)=((M*(1.0-(1.0/(2.0**K))*(1.0/RATIOS(I))))*XL)+C
125   CONTINUE
      K=K+1

150   CONTINUE

      PRINT*
      PRINT*,'Do you want to calculate mouth-widths? Y/N'
      READ'(A1)',REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
         PRINT*,'Do you wish to enter the mouth width as'
         PRINT*,'1. a ratio of pipe  circumference or '
         PRINT*,'2. in millimeteres?'
         PRINT*
         PRINT'(1H&,A)','Enter 1 or 2      '
         READ*,I

           IF (I .EQ. 1) THEN
```

```
      PRINT*
      MW(1)=(2*PI*((Y(1)/2)))/WIDIAM
      WRITE(6,155) MW(1), WIDIAM
155   FORMAT('The mouth width of the larger pipe is',F9.3,'mm',/
     +,'and its ratio to the circumference of',F9.3)
      PRINT*
      PRINT*,'                    SMALLER PIPE'
      PRINT*,'Do you want to calculate the mouth-width : circumf
     +erence'
      PRINT'(1H&,A)','ratio from known data? (Y/N)'
      READ'(A1)',REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y'))THEN
         CALL MWRAT
         GOTO 160
      ELSE
         CALL MWCRC
      ENDIF
160      PRINT*
         PRINT'(1H&,A)','Enter the ratio as a decimal for the sm
     +aller pipe'
         READ (5,*) SIZE2
         MW(K13)=(2*PI*(Y(K13)/2))/SIZE2
         GOTO 170

    ELSE

      PRINT*
      PRINT'(1H&,A)','Enter the mouth-width of the larger pipe'
      READ*,MW(1)
      PRINT*
      PRINT'(1H&,A)','Enter the mouth-width of the smaller pipe'
      READ*,MW(K13)
      GOTO 170
    ENDIF

170   CMW=MW(1)
      MMW=(MW(K13)-CMW)/(XL/2)

      K=0
      DO 250 IL=1,KTOP,12
      NL=IL+12

      DO 200 I=IL,NL
      MW(I)=((MMW*(1.0-(1.0/(2.0**K))*(1.0/RATIOS(I))))*XL)+CMW
200   CONTINUE
      K=K+1

250   CONTINUE

   ELSE
      GOTO 500
   ENDIF

   PRINT*
   PRINT'(1H&,A)','Do you want to calculate mouth-heights? Y/N'
   READ'(A1)',REPLY

   IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
```

```
      PRINT*,'Do you wish to enter the mouth height as'
      PRINT*,'1. a ratio of mouth width, or '
      PRINT*,'2. in millimeteres?'
      PRINT*
      PRINT'(1H&,A)','Enter 1 or 2      '
      READ*,J

      IF (J .EQ. 1) THEN
           PRINT*
           PRINT*
           MH(1)=MW(1)/WIDTH
           WRITE(6,260) MH(1), WIDIAM
260        FORMAT('The mouth height of the larger pipe is',F9.3,'mm',
     +/,'and its ratio to the mouth width is',F9.3 //)
           PRINT*
           PRINT*,'                   SMALLER PIPE'
         PRINT'(1H&,A)','Do you want to calculate the mouth ratio fro
     +m known data?  (Y/N)'
         READ'(A1)',REPLY

         IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
            CALL MORAT
         ELSE
            CALL TABLE1
         ENDIF

         PRINT*
         PRINT'(1H&,A)','Enter the mouth-ratio as a decimal for the s
     +maller pipe'
         READ (5,*) CUTUP2
         MH(K13)=MW(K13)/CUTUP2
         GOTO 270

      ELSE

         PRINT*
         PRINT'(1H&,A)','Enter the mouth-height of the larger pipe'
         READ*,MH(1)
         PRINT*
         PRINT'(1H&,A)','Enter the mouth-height of the smaller pipe'
         READ*,MH(K13)
         GOTO 270

      ENDIF

270   CMH=MH(1)
      MMH=(MH(K13)-CMH)/(XL/2)

      K=0
      DO 350 KJ=1,KTOP,12
      NJ=KJ+12

      DO 300 I=KJ,NJ
      MH(I)=((MMH*(1.0-(1.0/(2.0**K))*(1.0/RATIOS(I))))*XL)+CMH
300   CONTINUE
      K=K+1

350   CONTINUE
```

```
         PRINT*
         PRINT*,'Enter the name of file for output'
         PRINT*,'Pressing [RETURN] will mean the filename -BEDOS'
         PRINT*,'is assumed.'
         PRINT'(1H&,A)','DATAFILE:  '
         READ '(A12)',BEDFIL
         IF (BEDFIL .EQ. '            ') BEDFIL= '-BEDOS'
         CALL FTNCMD ('ASSIGN 30='// BEDFIL //';')
         CALL EMPTYF (30)
         REWIND (30)
         WRITE (30,400) (Y(I),MW(I),MH(I),I=1,KTOP)
         PRINT*,'DIAMETER         MOUTH WIDTH         MOUTH HEIGHT'
         WRITE (5,400) (Y(I),MW(I),MH(I),I=1,KTOP)
400      FORMAT (3(5X,F9.3))
         GOTO 999

      ELSE
         GOTO 500
      ENDIF

500   WRITE(6,600) (Y(I),I=1,KTOP)
600   FORMAT (F9.3)

999   STOP
      END
C
C Subroutine: calculation of mouth ratios
C
      SUBROUTINE MORAT
      PRINT*
      PRINT*,'In order to enter the mouth-width as a decimal, you'
      PRINT*,'may calculate the decimal from known measurements'
      PRINT*
      PRINT'(1H&,A)','Enter the mouth width of the pipe (in mm)'
      READ(5,*) AMWTH
      PRINT*
      PRINT'(1H&,A)','Now enter the mouth height (in mm)'
      READ(5,*) BMHT
      WIDTH=AMWTH/BMHT
      WRITE(5,10) WIDTH
10    FORMAT(/,'&MOUTH RATIO EXPRESSED AS A DECIMAL IS',F12.6,/)
      RETURN
      END
C
C Subroutine: calculation of mouth-width : circumference ratio
C
      SUBROUTINE MWRAT
      REAL WIDIAM,WIDTH
      INTEGER JNUMB
      DOUBLE PRECISION PIPL2(108),D(108),PI
      COMMON PIPL2,D,WIDIAM,WIDTH,JNUMB
      PARAMETER(PI=3.14159265358979323846)

      PRINT*
      PRINT*,'In order to enter the mouth-width : circumference as a de
     +cimal,'
      PRINT*,'you may calculate the decimal from known measurements'
      PRINT*
```

```
      PRINT'(1H&,A)','Enter the mouth-width of the pipe (in mm)'
      READ(5,*) AMWTH
      PRINT*
      PRINT'(1H&,A)','Enter the diameter of the pipe (in mm)'
      READ(5,*)  D(1)
      RADIUS=D(1)/2
      WIDIAM=(2.0*RADIUS*PI)/AMWTH
      WRITE(5,20) WIDIAM
20    FORMAT(/,'&MOUTH-WIDTH : CIRCUMFERENCE RATIO EXPRESSED AS A DECIMA
     +L IS',F12.6,/)
      RETURN
      END
C
C
C *****************************************************************
C *       SUBROUTINE ARROW : PRINCIPAL VARIABLES                  *
C *                                                               *
C *       Mouth ratio calculated as             WIDTH             *
C *       Ratio of mouth width:circumference    WIDIAM            *
C *       Temperature in degrees  K             TEMPOK            *
C *       Speed of sound (m per sec)            C                 *
C *       Eccentricity of ellipse (e)           E                 *
C *       Elliptic function K(e)                DKE               *
C *       K(e)/0.89                             XX                *
C *       Pipe Diameter                         D                 *
C *       Radius (R2)                           R2                *
C *       Mouth width                           LAB               *
C *       Mouth height                          HTMTH             *
C *       Radius (R1)                           R1                *
C *       Frequency (Hz)                        SCALE             *
C *       Wave number                           AK                *
C *       Plate width                           PLWTH             *
C *       Half plate width                      HPLWTH            *
C *       Cross-sectional area                  AREA              *
C *       Open end correction (.61r)            ENDCOR            *
C *       COT(KL) (without K(e)/0.89)           COTKL             *
C *       L1                                    PIPEL2            *
C *       L2                                    DL1               *
C *       Effective length                      PIPEL1            *
C *       Computed length                       DL1L2             *
C *       Quality factor                        QF                *
C *       COT(KL) (with K(e)/0.89)              TOT               *
C *       L 2             } with                TUBEL2            *
C *       Computed length } COT(KL)             PIPL2             *
C *                                                               *
C *                                                               *
C *****************************************************************
      SUBROUTINE ARROW

      REAL LAB(108),HTMTH(108),PLWTH(108),HPLWTH(108),AREA(108),QF(108)
      REAL WIDIAM,WIDTH

      INTEGER KOUNT(108),JNUMB

      DOUBLE PRECISION D(108), SCALE(108),TEMPOK,C,AK(108),R1(108),R2(10
     :8),DKE(108),PIPEMM(108),PIPEL1(108),XX(108),COTKL(108),PIPEL2(108)
     :,ENDCOR(108),DL1(108),DL1L2(108),E(108),E2(108),EZ(108),Q(108),Z(1
     :08),STONE,CAV(108),DOG(108),VAC(108),COLL(108),LLOC(108),DXXX(108)
```

```
     :,DCENT(108),PCENT(108),DM(108),PI,TOT(108),TUBEL2(108),PIPL2(108),
     :NEWWID(108),NEWMWC(108)

      CHARACTER REPLY*1,ONEREP*1,REPLY1*1

      COMMON PIPL2,D,WIDIAM,WIDTH,JNUMB

      PARAMETER(PI=3.14159265358979323846)

C  Constants

      A=-1.0
      B=-0.5
      CONV=0.394
      ZERO=0.0
      KOUNT(1)=1

1     PRINT*
      PRINT*,'    ***********  CALCULATION OF PIPE SERIES ***********'
      PRINT*
      PRINT*,'You may calculate pipe dimensions for the following pipe t
     1ypes:'
      PRINT*
      PRINT*,' 1.  Logarithmic scaling after Sorge and Toepfer'
2     PRINT*,' 2.  Fixed-variable scales after Dom Bedos'
      PRINT*
      PRINT'(1H&,A)','Enter 1 2  (or 0 to stop)'
      READ(5,*) I
      IF (I .EQ. 0) GOTO 6000
      IF (I .EQ. 1) GOTO 6
      IF (I .EQ. 2) GOTO 6
      GOTO 1

6     PRINT*
      PRINT'(1H&,A)','What is the diameter of the reference pipe ? (mm)'
      READ (5,*) D(1)

      PRINT*
8     PRINT'(1H&,A)','Enter the temperature in degrees C'
      READ(5,*) TEMPOC

C  Calculate the speed of sound according to temperature.

      TEMPOK=(TEMPOC+273.15)
      C=(DSQRT(1.40*287.10*TEMPOK))

      PRINT*
C     Calculate constant semitone interval
      STONE=2.0**(1.0/12.0)

      CALL TABLE3
      PRINT*
      PRINT'(1H&,A)','Enter the frequency of the lowest C pitch'
      READ(5,*) SCALE(1)

      PRINT*
      PRINT'(1H&,A)','Do you want to calculate the mouth ratio from know
     1n data?  (Y/N)'
```

```
      READ'(A1)',REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
10      CALL MORAT
      ELSE
        CALL TABLE1
      ENDIF

      PRINT*
      PRINT'(1H&,A)','Enter the desired mouth-ratio as a decimal...'
      READ (5,*) WIDTH

      AB=1.0/WIDTH

      PRINT*
      PRINT*,'Do you want to calculate the mouth-width : circumference'
      PRINT'(1H&,A)','ratio from known data? (Y/N)'
      READ'(A1)',REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y'))THEN
         CALL MWRAT
      ELSE
         CALL MWCRC
      ENDIF

      PRINT*
      PRINT'(1H&,A)','Enter the ratio as a decimal'
      READ (5,*) WIDIAM

C If Bedos scaling method is requested, then the control variable
C ONEREP is set to answer NO.
      IF (I .EQ. 2) THEN
         ONEREP='N'
         GOTO 20
      ENDIF

      PRINT*
      PRINT'(1H&,A)','Do you want to calculate a series? (Y/N)'
      READ'(A1)',ONEREP
      IF ((ONEREP .EQ. 'Y') .OR. (ONEREP .EQ. 'y')) THEN
        CALL TABLE2
        PRINT'(1H&,A)','21.5     1:1.25  (4:5)      Enter the Semitone h
     lalving step'
        READ (5,*) SCFAC

        PRINT*
        PRINT'(1H&,A)','For how many octaves do you want scalings?'
        READ (5,*) JOCT
        JNUMB=JOCT*12
        IF (JNUMB .GT. 108) THEN
          PRINT*
          PRINT*,'NO MORE THAN 10 OCTAVES - No output generated !'
          STOP
         ENDIF
      ELSE
         GOTO 20
      ENDIF

20    R2(1)=(D(1)/2)
      LAB(1)=((2*PI*R2(1))/WIDIAM)
```

```
      HTMTH(1)=LAB(1)/WIDTH
C
C     Calculate the radius (R1) in the circular opening of the same area
C     as the mouth of the pipe
C
      R1(1)=(DSQRT(LAB(1)*HTMTH(1)/PI))
C
C     Calculate the wave number
C
      AK(1)=((2*PI*SCALE(1))/(C*1000.00))
C
C     Platewidths & area
C
      PLWTH(1)=(2*PI*R2(1))
      HPLWTH(1)=(PLWTH(1)/2)
      AREA(1)=PI*(D(1)**2)
      ENDCOR(1)=0.6133*R2(1)
C
C     Elliptic funtion of the first order   K(e) = DKE
C     Calculate eccentricity of ellipse (e)
C
      E(1)=SQRT(1.0-((AB)**2))
C
C     Calculate the elliptic function
C
      E2(1)=DSQRT(1.0-(E(1)**2))
      EZ(1)=((1.0-(DSQRT(E2(1))))/(1+(DSQRT(E2(1))))/2.0)
      Q(1)=EZ(1)+(2.0*(EZ(1)**5.0))
      DKE(1)=((1.0+(Q(1)*2.0)+(2.0*(Q(1)**4.0)))**2)*(1.0-(E(1
     1)**2.0))**(AB)
C
C     Calculate effective pipe length
C
      PIPEMM(1)=(C/(2*SCALE(1)))
      PIPEL1(1)=PIPEMM(1)*1000.00
C
C     Equation 3.07 Frobenius & Ingerslev
C
      XX(1)=DKE(1)/0.89
      COTKL(1)=1.30*R1(1)*(PI*(R2(1)**2))/(HTMTH(1)*LAB(1))
      TOT(1)=COTKL(1)*XX(1)
C
C     Calculate l(2) of pipe, NO conversion of angle in degrees to radian
C     measure using (PI/180) ARCTAN is used instead of INVERSE TAN
C
      PIPEL2(1)=(DATAN(1.0/(COTKL(1)*AK(1))))/AK(1)
      TUBEL2(1)=(DATAN(1.0/(TOT(1)*AK(1))))/AK(1)
C
C     Final calculations: end correction at top, and computed length
C
      DL1(1)=(PIPEL1(1)/2)-ENDCOR(1)
      DL1L2(1)=DL1(1)+PIPEL2(1)
      PIPL2(1)=DL1(1)+TUBEL2(1)
C
C     Quality factor equation (Benade)
C
      QF(1)=((5 E -5)*SCALE(1)*((D(1)/10.0)**2)*((PIPL2(1)/10.0)**A)+(1.
     :40*(SCALE(1)**B))*((D(1)/10.0)**A)**A)
```

```
C
C
      IF (I .EQ. 2) GOTO 161
      IF ((ONEREP .EQ. 'Y') .OR. (ONEREP .EQ. 'y')) THEN


      PRINT*
      PRINT'(1H&,A)','Do you want to add a constant for fixed-variable s
     1cales? (Y/N)'
      READ'(A1)',REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y'))THEN
         PRINT*
         PRINT*,'You may enter the constant as a % of pipe diameter (1)
     1or in mm (2)'
         PRINT*,'or in single values (in mm) for each note (3)'
         PRINT'(1H&,A)','Answer (1), (2) or (3)'
         READ(5,*) P1
         IF ((P1 .EQ. 2) .OR. (P1 .EQ. 3)) GOTO 50
         PRINT*
         PRINT'(1H&,A)','Enter the constant as an % increase in pipe dia
     1meter'
         READ(5,*) ZCENT
      ELSE
      GOTO 125
      END IF

      NEWWID(1)=WIDTH
      DO 40 I=2,JNUMB
      DCENT(I)=D(1)/(2**((I-1)/SCFAC))
      PCENT(I)=DCENT(I)*(ZCENT/100)
      D(I)=PCENT(I)+DCENT(I)
         NEWWID(I)=WIDTH
         R2(I)=(D(I)/2)
         LAB(I)=((2*PI*R2(I))/WIDIAM)
         HTMTH(I)=LAB(I)/WIDTH
 40   CONTINUE
      GOTO 150

 50   IF (P1 .EQ. 3) GOTO 90

      PRINT*
      PRINT'(1H&,A)','Enter the constant (in mm)'
      READ(5,*) QP

      DO 70 I=2,JNUMB
      DXXX(I)=D(1)/(2**((I-1)/SCFAC))
      D(I)=DXXX(I)+QP
 70   CONTINUE
 80   GOTO 150
 90   DO 120 I=2,JNUMB
      DM(I)=D(1)/(2**((I-1)/SCFAC))
      WRITE(6,100)I,DM(I)
 100  FORMAT(/,'&The Diameter for semitone number ',I5,'  is ',F9.2)
      PRINT*
      PRINT'(1H&,A)','Enter the constant (in mm)'
      READ(5,*)INPT
      D(I)=DM(I)+INPT
      WRITE(6,110)D(I)
```

```
110   FORMAT(/,'&THE DIAMETER IS NOW',F9.2,//)
120   CONTINUE
      GOTO 150

125   DO 140 I=2,JNUMB
      D(I)=D(1)/(2**((I-1)/SCFAC))
140   CONTINUE

      PRINT*
      PRINT'(1H&,A)','Do you want to add a new mouth-width ratio for eac
     1h pipe? (Y/N)'
      READ'(A1)',REPLY1
      IF ((REPLY1 .EQ. 'Y') .OR. (REPLY1 .EQ. 'y'))THEN
         NEWWID(1)=WIDTH
         DO 142 I=2,JNUMB
         PRINT*
         WRITE(6,130) I,D(I)
130      FORMAT(/,'&Diameter for semitone number',I5,' is',F9.2,' mm')
         PRINT*
         PRINT'(1H&,A)','Enter the new mouth ratio as a decimal'
         READ(5,*) NEWWID(I)
142      CONTINUE
      ELSE
         NEWWID(1)=WIDTH
         DO 143 I=2,JNUMB
         NEWWID(I)=WIDTH
         R2(I)=(D(I)/2)
         LAB(I)=((2*PI*R2(I))/WIDIAM)
         HTMTH(I)=LAB(I)/WIDTH
143      CONTINUE
      ENDIF

      PRINT*
      PRINT'(1H&,A)','Do you want to add a new mouth-width : circumferen
     +ce ratio for each pipe? (Y/N)'
      READ'(A1)',REPLY1
      IF ((REPLY1 .EQ. 'Y') .OR. (REPLY1 .EQ. 'y'))THEN
         NEWMWC(1)=WIDIAM
         DO 146 I=2,JNUMB
         PRINT*
         WRITE(6,139) I,D(I)
139      FORMAT(/,'&Diameter for semitone number',I5,' is',F9.2,' mm')
         PRINT*
         PRINT'(1H&,A)','Enter the new mouth : circumference ratio as a
     +decimal'
         READ(5,*) NEWMWC(I)
146      CONTINUE
      ELSE
         NEWMWC(1)=WIDIAM
         DO 147 I=2,JNUMB
         NEWMWC(I)=WIDIAM
         R2(I)=(D(I)/2)
         LAB(I)=((2*PI*R2(I))/WIDIAM)
         HTMTH(I)=LAB(I)/WIDTH
147      CONTINUE
      ENDIF

      IF ((REPLY1 .EQ. 'Y') .OR. (REPLY1 .EQ. 'y')) THEN
```

1

```
           DO 148 I=2,JNUMB
           R2(I)=D(I)/2
           LAB(I)=((2*PI*R2(I))/NEWMWC(I))
           HTMTH(I)=LAB(I)/NEWWID(I)
148        CONTINUE
        ELSE
           GOTO 150
        ENDIF

150     DO 160 I=2,JNUMB
C
C       Calculate the radius (R1) in the circular opening of the same area
C       as the mouth of the pipe
C
        R1(I)=(DSQRT(LAB(I)*HTMTH(I)/PI))
C
C       Calculate the frequencies
C
        SCALE(I)=SCALE(I-1)*STONE
C
C       Calculate the wave number
C
        AK(I)=((2*PI*SCALE(I))/(C*1000.00))
C
C       Platewidths & area
C
        PLWTH(I)=(2*PI*R2(I))
        HPLWTH(I)=(PLWTH(I)/2)
        AREA(I)=PI*(D(I)**2)
        ENDCOR(I)=0.6133*R2(I)
C
C       Elliptic funtion of the first order   K(e) = DKE
C       Calculate eccentricity of ellipse (e)
C
        E(I)=SQRT(1.0-((AB)**2))
C
C       Calculate the elliptic function
C
        E2(I)=DSQRT(1.0-(E(I)**2))
        EZ(I)=((1.0-(DSQRT(E2(I))))/(1+(DSQRT(E2(I))))/2.0)
        Q(I)=EZ(I)+(2.0*(EZ(I)**5.0))
        DKE(I)=((1.0+(Q(I)*2.0)+(2.0*(Q(I)**4.0)))**2)*(1.0-(E(I
       1)**2.0))**(AB)
C
C       Calculate effective pipe length
C
        PIPEMM(I)=(C/(2*SCALE(I)))
        PIPEL1(I)=PIPEMM(I)*1000.00
C
C       Equation 3.07 Frobenius & Ingerslev
C
        XX(I)=DKE(I)/0.89
        COTKL(I)=1.30*R1(I)*(PI*(R2(I)**2))/(HTMTH(I)*LAB(I))
        TOT(I)=COTKL(I)*XX(I)
C
C       Calculate l(2) of pipe, NO conversion of angle in degrees to radian
C       measure using (PI/180) ARCTAN is used instead of INVERSE TAN
C
```

```
      PIPEL2(I)=(DATAN(1.0/(COTKL(I)*AK(I))))/AK(I)
      TUBEL2(I)=(DATAN(1.0/(TOT(I)*AK(I))))/AK(I)
C
C     Final calculations: end correction at top, and computed length
C
      DL1(I)=(PIPEL1(I)/2)-ENDCOR(I)
      DL1L2(I)=DL1(I)+PIPEL2(I)
      PIPL2(I)=DL1(I)+TUBEL2(I)
C
C     Quality factor equation (Benade)
C
      QF(I)=((5 E -5)*SCALE(I)*((D(I)/10.0)**2)*((PIPL2(I)/10.0)**A)+(1.
     :40*(SCALE(I)**B))*((D(I)/10.0)**A)**A)

C
C     SIMPLE COUNTER FOR INDEXING FILES
C
      KOUNT(I)=I
C
160   CONTINUE
      ELSE
        GOTO 161
      ENDIF


161   IF ((ONEREP .EQ. 'N') .OR. (ONEREP .EQ. 'n')) THEN
        CALL FTNCMD('ASSIGN 13=-RESULT;')
        REWIND (13)
        WRITE (6,1000) WIDTH
        WRITE (6,1010) WIDIAM
        WRITE (6,1020) TEMPOK
        WRITE (6,1030) C
        WRITE (6,1040) E(1)
        WRITE (6,1050) DKE(1)
        WRITE (6,1060) XX(1)
        WRITE (6,1070) D(1)
        WRITE (6,1080) R2(1)
        WRITE (6,1090) LAB(1)
        WRITE (6,1100) HTMTH(1)
        WRITE (6,1110) R1(1)
        WRITE (6,1120) SCALE(1)
        WRITE (6,1130) AK(1)
        WRITE (6,1140) PLWTH(1)
        WRITE (6,1150) HPLWTH(1)
        WRITE (6,1160) AREA(1)
        WRITE (6,1170) ENDCOR(1)
        WRITE (6,1210) PIPEL2(1)
        WRITE (6,1230) PIPEL1(1)
        WRITE (6,1250) QF(1)
        WRITE (6,1260) TOT(1)
        WRITE (6,1270) TUBEL2(1)
        WRITE (6,1280) PIPL2(1)
C
        WRITE (13,1000) WIDTH
        WRITE (13,1010) WIDIAM
        WRITE (13,1020) TEMPOK
        WRITE (13,1030) C
        WRITE (13,1040) E(1)
```

```
          WRITE (13,1050) DKE(1)
          WRITE (13,1060) XX(1)
          WRITE (13,1070) D(1)
          WRITE (13,1080) R2(1)
          WRITE (13,1090) LAB(1)
          WRITE (13,1100) HTMTH(1)
          WRITE (13,1110) R1(1)
          WRITE (13,1120) SCALE(1)
          WRITE (13,1130) AK(1)
          WRITE (13,1140) PLWTH(1)
          WRITE (13,1150) HPLWTH(1)
          WRITE (13,1160) AREA(1)
          WRITE (13,1170) ENDCOR(1)
          WRITE (13,1210) PIPEL2(1)
          WRITE (13,1230) PIPEL1(1)
          WRITE (13,1250) QF(1)
          WRITE (13,1260) TOT(1)
          WRITE (13,1270) TUBEL2(1)
          WRITE (13,1280) PIPL2(1)
1000      FORMAT (//5X,'Mouth ratio calculated as        ',F9.5)
1010      FORMAT (5X,'Ratio of mouth-width:circumf.   ',F9.5)
1020      FORMAT (5X,'Temperature in degrees  K       ',F9.5)
1030      FORMAT (5X,'Speed of sound (m per sec)      ',F9.5)
1040      FORMAT (5X,'Eccentricity of ellipse (e)       ',F6.4)
1050      FORMAT (5X,'Elliptic function K(e)            ',F5.3)
1060      FORMAT (5X,'K(e)/0.89                        ',F8.3)
1070      FORMAT (5X,'Pipe Diameter (mm)              ',F9.2)
1080      FORMAT (5X,'Radius (R2) (mm)                ',F9.2)
1090      FORMAT (5X,'Mouth width (mm)                ',F9.2)
1100      FORMAT (5X,'Mouth height (mm)               ',F9.2)
1110      FORMAT (5X,'Radius (R1) (mm)                ',F9.2)
1120      FORMAT (5X,'Frequency (Hz)                  ',F9.2)
1130      FORMAT (5X,'Wave number                        ',F8.5)
1140      FORMAT (5X,'Plate width (mm)                 ',F8.3)
1150      FORMAT (5X,'Half plate width (mm)            ',F8.3)
1160      FORMAT (5X,'Cross-sectional area (sq mm) ',F10.2)
1170      FORMAT (5X,'Open end correction (.6133r) mm',F8.3)
1210      FORMAT (5X,'L1 (mm)                         ',F9.2)
1230      FORMAT (5X,'Effective length (mm)           ',F9.2)
1250      FORMAT (5X,'Quality factor                   ',F9.6)
1260      FORMAT (5X,'COT(KL) (with K(e)/0.89)        ',F9.2)
1270      FORMAT (5X,'L 2                } with    (mm)',F9.2)
1280      FORMAT (5X,'Computed length } COT(KL) (mm)',F9.2)
          PRINT*
          PRINT*,'-RESULT CONTAINS A COPY OF THIS RUN'
          IF (I .EQ. 2) THEN
             CALL BEDOS
          ELSE
             GOTO 6000
          ENDIF
        ENDIF

        CALL FTNCMD('ASSIGN 11=-SCALE;')
        CALL FTNCMD('ASSIGN 12=-LOG;')
        CALL FTNCMD('ASSIGN 14=-LENGTH;')
        CALL FTNCMD('ASSIGN 19=-OCTS;')
        REWIND (11)
        REWIND (12)
```

```
      REWIND (14)
      REWIND (19)

      PRINT*
      PRINT'(1H&,A)','Do you want to view the scales on the screen? (Y/N
     1)'
        READ'(A1)',REPLY
        IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
        WRITE (6,1299) JNUMB
        WRITE (6,1300) SCFAC
        WRITE (6,1400) WIDTH
        WRITE (6,1425) WIDIAM
        WRITE (6,1450) TEMPOK
        WRITE (6,1475) C
        WRITE (6,1480) E(1)
        WRITE (6,1485) DKE(1)
        WRITE (6,1490) XX(1)
        WRITE (6,1500)
        WRITE (6,2000) (D(I),R2(I),LAB(I),HTMTH(I),R1(I),I=1,JNUMB)
        WRITE (6,1510)
        WRITE (6,3000) (SCALE(I),AK(I),PLWTH(I),HPLWTH(I),AREA(I),I=1,JN
     1UMB)
        WRITE (6,1520)
        WRITE (6,4000) (ENDCOR(I),TOT(I),DL1(I),TUBEL2(I),I=1,JNUMB)
        WRITE (6,1530)
        WRITE (6,5000) (PIPL2(I),PIPEL1(I),NEWWID(I),NEWMWC(I),QF(I),I=1
     :,JNUMB)
      ENDIF
      WRITE (11,1299) JNUMB
      WRITE (11,1300) SCFAC
      WRITE (11,1400) WIDTH
      WRITE (11,1425) WIDIAM
      WRITE (11,1450) TEMPOK
      WRITE (11,1475) C
      WRITE (11,1480) E(1)
      WRITE (11,1485) DKE(1)
      WRITE (11,1490) XX(1)
      WRITE (11,1500)
1299  FORMAT(/5X,'Total number of calculations is',2X,I3)
1300  FORMAT (5X,'Diameter halving on step',2X,F4.1)
1400  FORMAT (5X,'Mouth ratio calculated as       ',F9.5)
1425  FORMAT (5X,'Ratio of mouth width:diameter   ',F9.5)
1450  FORMAT (5X,'Temperature in degrees  K       ',F9.5)
1475  FORMAT (5X,'Speed of sound (m per sec)      ',F9.5)
1480  FORMAT (5X,'Eccentricity of ellipse (e)       ',F6.4)
1485  FORMAT (5X,'Elliptic function K(e)            ',F5.3)
1490  FORMAT (5X,'K(e)/0.89                       ',F8.3)
1500  FORMAT(//12X,'DIAMETER',4X,'RADIUS(R2)',2X,'MOUTH WIDTH',2X,'MOUTH
     1 HEIGHT',2X,'RADIUS(R1)')
      WRITE(11,2000) (D(I),R2(I),LAB(I),HTMTH(I),R1(I),I=1,JNUMB)
C Write pipe scale and index for plotting to I/O units 12,14,19
      WRITE (12,1506) (KOUNT(I),D(I),I=1,JNUMB)
      WRITE (14,1506) (KOUNT(I),PIPL2(I),I=1,JNUMB)
      WRITE (19,1507) (D(I),I=1,JNUMB)
1506  FORMAT (I3,5X,F9.2)
1507  FORMAT (F9.2)
C
      WRITE(11,1510)
```

```
1510  FORMAT(//12X,'FREQUENCY',4X,'WAVE NUMB',2X,'PLATE WIDTH',3X,'PLWTH
     1/2',3X,'X-SECT AREA')
      WRITE(11,3000) (SCALE(I),AK(I),PLWTH(I),HPLWTH(I),AREA(I),I=1,JNUM
     1B)
      WRITE(11,1520)
1520  FORMAT(//9X,'OPEN END COR',4X,'COTKL',10X,'L1',10X,'L2')
      WRITE (11,4000) (ENDCOR(I),TOT(I),DL1(I),TUBEL2(I),I=1,JNUMB)
      WRITE (11,1530)
1530  FORMAT(//9X,'COMP. LENGTH',3X,'EFF. LENGTH',2X,'M/W RATIOS',2X,'M
     +/W/C RATIOS',3X,'QUAL FAC')
      WRITE (11,5000) (PIPL2(I),PIPEL1(I),NEWWID(I),NEWMWC(I),QF(I),I=1,
     1JNUMB)

2000  FORMAT(100(5X,'C',5(4X,F9.2),/,1X,'C£/Db',5(4X,F9.2),/,5X,'D',5(4X
     +,F9.2),/,1X,'D£/Eb',5(4X,F9.2),/,5X,'E',5(4X,F9.2),/,5X,'F',5(4X,F
     +9.2),/,1X,'F£/Gb',5(4X,F9.2),/,5X,'G',5(4X,F9.2),/,1X,'G£/Ab',5(4X
     +,F9.2),/,5X,'A',5(4X,F9.2),/,1X,'A£/Bb',5(4X,F9.2),/,5X,'B',5(4X,F
     +9.2),//))
3000  FORMAT(100(5X,'C',4X,F9.2,6X,F8.5,2(4X,F8.3),3X,F10.2,/,1X,'C£/Db'
     +,4X,F9.2,6X,F8.5,2(4X,F8.3),3X,F10.2,/,5X,'D',4X,F9.2,6X,F8.5,2(4X
     +,F8.3),3X,F10.2,/,1X,'D£/Eb',4X,F9.2,6X,F8.5,2(4X,F8.3),3X,F10.2,/
     +,5X,'E',4X,F9.2,6X,F8.5,2(4X,F8.3),3X,F10.2,/,5X,'F',4X,F9.2,6X,F8
     +.5,2(4X,F8.3),3X,F10.2,/,1X,'F£/Gb',4X,F9.2,6X,F8.5,2(4X,F8.3),3X,
     +F10.2,/,5X,'G',4X,F9.2,6X,F8.5,2(4X,F8.3),3X,F10.2,/,1X,'G£/Ab',4X
     +,F9.2,6X,F8.5,2(4X,F8.3),3X,F10.2,/,5X,'A',4X,F9.2,6X,F8.5,2(4X,F8
     +.3),3X,F10.2,/,1X,'A£/Bb',4X,F9.2,6X,F8.5,2(4X,F8.3),3X,F10.2,/,5X
     +,'B',4X,F9.2,6X,F8.5,2(4X,F8.3),3X,F10.2,//))
4000  FORMAT(100(5X,'C',4(4X,F9.2),/,1X,'C£/Db',4(4X,F9.2),/,5X,'D',4(4X
     +,F9.2),/,1X,'D£/Eb',4(4X,F9.2),/,5X,'E',4(4X,F9.2),/,5X,'F',4(4X,F
     +9.2),/,1X,'F£/Gb',4(4X,F9.2),/,5X,'G',4(4X,F9.2),/,1X,'G£/Ab',4(4X
     +,F9.2),/,5X,'A',4(4X,F9.2),/,1X,'A£/Bb',4(4X,F9.2),/,5X,'B',4(4X,F
     +9.2),//))
5000  FORMAT(100(5X,'C',4(4X,F9.2),4X,F9.6,/,1X,'C£/Db',4(4X,F9.2),4X,F9
     +.6,/,5X,'D',4(4X,F9.2),4X,F9.6,/,1X,'D£/Eb',4(4X,F9.2),4X,F9.6,/,5
     +X,'E',4(4X,F9.2),4X,F9.6,/,5X,'F',4(4X,F9.2),4X,F9.6,/,1X,'F£/Gb',
     +4(4X,F9.2),4X,F9.6,/,5X,'G',4(4X,F9.2),4X,F9.6,/,1X,'G£/Ab',4(4X,F
     +9.2),4X,F9.6,/,5X,'A',4(4X,F9.2),4X,F9.6,/,1X,'A£/Bb',4(4X,F9.2),4
     +X,F9.6,/,5X,'B',4(4X,F9.2),4X,F9.6,//))

      PRINT*
      PRINT*,'-SCALE CONTAINS A COPY OF THIS RUN'
      PRINT*,'-LOG CONTAINS AN INDEXED COPY OF THE PIPE SCALE ONLY'
      PRINT*,'-LENGTH CONTAINS AN INDEXED COPY OF THE PIPE LENGTH ONLY'
      PRINT*,'-OCTS CONTAINS COPY OF THE PIPE SCALE ONLY'
      PRINT*
      PRINT'(1H&,A)','Do you want to plot the results? (Y/N)'
      READ '(A1)', REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
         CALL GRAPH
      ENDIF
6000  RETURN
      END
C ***********************************************************************
C ***********************************************************************
C *                                                                     *
C *         Organ Pipe Characteristic Plotting Routine                  *
C *                                                                     *
C *          udate: 28.6.87                                             *
```

```
C *                                                                      *
C ***********************************************************************
C ***********************************************************************
      SUBROUTINE GRAPH
C variables
      REAL  CDIA(1:10), NMPLOT(1:5,1:10), LOOKUP(1:10)
      REAL  UPLIM, LOLIM, HI, U, L, XLO, XHI, YLO, YHI, CORFAC
      REAL WIDIAM,WIDTH
C
      DOUBLE PRECISION PIPL2(108),D(108)
C
      CHARACTER REPLY, LABEL*60, NMLABL(1:10)*8, FLAGS*4, TEMP*4
      CHARACTER LEGEND(1:5)*60, INFILE*12, PLFILE*12, PLFREP*12
      CHARACTER INFIL1*12
      CHARACTER ROUND, SPREP, CONTFL*12, NEWREP*1, REPLY1*1
C
      INTEGER  SIGN, NP(1:5), I,J,K, FIRST(1:5), PLOT, BRARGS(1:5,1:4)
      INTEGER  OCTAVS, LOFST, JNUMB
C Common from ARROW
      COMMON PIPL2,D,WIDIAM,WIDTH,JNUMB
C
      ZERO=0.0
C
C initialising
C
      DATA LOOKUP /
     :261.5,155.5,92.416,54.978,32.69,19.43,11.558,6.872,4.086,2.43 /
C
      DATA UPLIM, LOLIM, OCTAVS, LOFST / 0.,0., 8, 10 /
      DATA CORFAC, ROUND / 0.0, 'N' /
C
      DATA BRARGS/
     :20, 15,  5 ,  5, 10,
     : 5,  5,  5 ,  2,  2,
     :20,  5,  5 ,  2,  2,
     :5 ,  5,  5 ,  5, 10/
C
      DATA NMLABL /
     :'CC','C','c','c1','c2','c3','c4','c5','c6','c7'/
C
      DATA INFILE, CONTFL, PLFILE / '*MSOURCE*','-OCTS', '-P' /
C Data for replies set at X until otherwise declared
      DATA SPREP /'X'/
      DATA NEWREP /'X'/
C
C execute
C
      PRINT'(1H1)'
      PRINT*,'Enter the name of the file for the graphical output.'
      PRINT*,'If you press [RETURN], -P is assumed as filename.'
      PRINT'(1H&,A)',   'PLOTFILE: '
      READ '(A12)', PLFREP
      IF (PLFREP .NE. '            ') PLFILE = PLFREP

      PRINT'(1H&,A)','Have you just generated the data? (Y/N)'
      READ '(A1)', SPREP
      IF ((SPREP .EQ. 'N') .OR. (SPREP .EQ. 'n')) THEN
         PRINT'(1H&,A)','Do you want to enter the data from a file? (Y/N
```

```
     1)'
         READ '(A1)', REPLY1
         IF ((REPLY1 .EQ. 'Y') .OR. (REPLY1 .EQ. 'y')) THEN
           PRINT*,'Enter the name of the data file.  Pressing [RETURN]'
           PRINT*,'will mean the filename NM.DATASET is assumed.'
           PRINT'(1H&,A)','DATAFILE: '
           READ '(A12)',INFILE
           IF (INFILE .EQ. '            ') INFILE = 'NM.DATASET'
C          ELSE IF ((REPLY1 .NE. 'N') .OR. (REPLY1 .NE. 'n')) THEN
           ELSE
           GOTO 19
         ENDIF
      ENDIF

      IF ((SPREP .EQ. 'Y') .OR. (SPREP .EQ. 'y')) THEN
         PRINT*,'Pressing [RETURN] will mean the filename -OCTS'
         PRINT*,'which contains intermediate values is assumed.'
         PRINT'(1H&,A)','DATAFILE: '
         READ '(A12)',CONTFL
          IF (CONTFL .EQ. '            ') CONTFL = '-OCTS'
      ENDIF
C
C ASSIGN I/O units & write selected items from array D(108) from ARROW into
C File -OCTS
C
      CALL FTNCMD ('ASSIGN 7='// INFILE  //';')
      CALL FTNCMD ('ASSIGN 8=-DAT;')
      CALL FTNCMD ('ASSIGN 9='// PLFILE  //';')
      CALL FTNCMD ('ASSIGN 10='// CONTFL  //';')
      CALL FTNCMD ('ASSIGN 11=-CONLY;')

      IF ((SPREP .EQ. 'Y') .OR. (SPREP .EQ. 'y')) THEN
        WRITE(11,FMT=12) (D(K),K=1,JNUMB,12),ZERO
        IF (JNUMB .LT. 24) THEN
           PRINT*,' *********** INSUFFICIENT DATA TO PLOT ***********'
           GOTO 9000
        ELSEIF (JNUMB .GT. 108) THEN
           GOTO 99
        ENDIF
      ENDIF

12    FORMAT(F9.2)

      PRINT'(1H&,A)','HT rounding (Y/N) '
      READ'(A1)', REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) ROUND='Y'
      PRINT'(1H&,A)','Title :  '
      READ  (7,FMT=15, END=99) LABEL
      WRITE(8,15) LABEL
15    FORMAT(A60 )
      PRINT*
      PLOT = 0
      PLOT = PLOT + 1
C If data just generated, then GOTO 22 (omitting reassigning I/O units
C until 41
      GOTO 22
C If REPLY1 = No, then jump from request to 19, setting counter
C (PLOT) to 0 and assigning I/O units missed out earlier. The
```

```
C programme continues as before & can loop back to 20 from 41
19    PLOT=0
C Counter for plot number
20    PLOT = PLOT + 1
C If data input via screen, then ASSIGN 8
      IF ((REPLY1 .EQ. 'N') .OR. (REPLY1 .EQ. 'n')) THEN
         CALL FTNCMD ('ASSIGN 7='// INFILE  //';')
         CALL FTNCMD ('ASSIGN 8=-DAT;')
         CALL FTNCMD ('ASSIGN 9='// PLFILE  //';')
      ENDIF
C On return from 41 to 21 counter is inremented by 1, SPREP (generated
C data) is set to NO to comply with questions & allow I/O 7 (*MSOURCE*)
C to read question at 30 automatically.
21    PLOT=PLOT + 1
      PRINT'(1H&,A)','Do you want to enter (more) diameters ? (Y/N)'
      READ'(A1)',NEWREP
      IF ((NEWREP .EQ. 'Y') .OR. (NEWREP .EQ. 'y')) THEN
         SPREP='N'
         PRINT*,'Enter the name of the data file.  Pressing [RETURN]'
         PRINT*,'will mean the data is accepted from the terminal'
         PRINT'(1H&,A)','Filename: '
         READ '(A12)', INFIL1
         IF (INFIL1 .EQ. '            ') INFIL1= '*MSOURCE*'
         CALL FTNCMD ('ASSIGN 7='// INFIL1 //';')
         READ  (7,FMT=15, END=99) LABEL
         WRITE (8,15) LABEL
      ELSE
        GOTO 41
      ENDIF

22    PRINT'(1H&,A,I1)','Legend label for plot ',PLOT,' :'
      READ (7, FMT=15, END=99) LEGEND (PLOT)
      WRITE(8,15) LEGEND (PLOT)
C
      PRINT '(1H&,A)','Correction factor (for tuning)? (Y/N):'
      READ '(A1)', REPLY
      IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) THEN
        PRINT '(1H&,A)','Enter the factor as a deviant from modern pitch
     1:'
        READ*, CORFAC
      ENDIF
C
      PRINT*
      PRINT'(1H&,A)','Octave offset (1=CC, 2=C, 3=c0, 4=c1 etc.) :'
      READ (7,FMT=32) FIRST (PLOT)
      WRITE(8,32) FIRST (PLOT)
32    FORMAT(I1)
C
      PRINT*
      IF (LOFST .GT. FIRST(PLOT)) LOFST = FIRST(PLOT)
      NP(PLOT) = 0
C
      IF ((NEWREP .EQ. 'N') .OR. (NEWREP .EQ. 'N')) GOTO 41
      IF ((SPREP .EQ. 'N') .OR. (SPREP .EQ. 'n')) THEN
30      PRINT*,'Enter C diameters (add 0 to end)'
        DO 33 I = 1,10
        READ(7,FMT=* ) CDIA (I)
        WRITE(8,37) CDIA(I)
```

```
37        FORMAT(F10.4)
          IF ( CDIA(I) .EQ. 0.) GOTO 35
          NP(PLOT) = I
33        CONTINUE
        ENDIF

C If data just generated, read from I/O 11
        IF ((SPREP .EQ. 'Y') .OR. (SPREP .EQ. 'y')) THEN
C Rewind 11 to eliminate possibility of reading previous runs
        REWIND (11)
        DO 34 I = 1,10
          READ(11,FMT=* ) CDIA (I)
          WRITE(8,36) CDIA (I)
36        FORMAT(F9.2)
          IF ( CDIA(I) .EQ. 0.) GOTO 35
          NP(PLOT) = I
34      CONTINUE
        ENDIF
C
35      CONTINUE
        DO 40 I = 1,NP(PLOT)
           J = I + FIRST (PLOT) - 1
           IF (LOOKUP(J) .LT. CDIA(I)) THEN
             NMPLOT(PLOT,I) = 16.0 * LOG( CDIA(I) / LOOKUP(J)) / LOG(2.0)
             SIGN = 1
           ELSE
             NMPLOT(PLOT,I) = 16.0 * LOG( LOOKUP(J) / CDIA(I)) / LOG(2.0)
             SIGN = -1
           ENDIF
        NMPLOT(PLOT,I) = (NMPLOT(PLOT,I) * SIGN) + CORFAC
          IF ((ROUND .EQ. 'Y') .OR. (ROUND .EQ. 'y')) THEN

          ENDIF
C
40      CONTINUE
41      PRINT*,'Do you want to plot results?'
        READ'(A1)',REPLY
        IF ((REPLY .EQ. 'Y') .OR. (REPLY .EQ. 'y')) GOTO 45
C       PRINT*,'  Ctrl-C to start plotting, or'
        GOTO 21
C
C i.e. loop back for another set
C
99      CONTINUE
        PLOT = PLOT - 1
        IF (PLOT .LT. 1) THEN
          PRINT*,'No output generated'
          STOP
         ENDIF
45      DO 50 I = 1, PLOT
        DO 50 J = 1, NP(I)
        IF(NMPLOT(I,J).GT.UPLIM) UPLIM = NMPLOT(I,J)
        IF(NMPLOT(I,J).LT.LOLIM) LOLIM = NMPLOT(I,J)
50      CONTINUE
C
        UPLIM = INT (UPLIM +1)
        LOLIM = INT (LOLIM -1)
C
```

```
      IF (UPLIM .LT.  2.) UPLIM = 2.
      IF (LOLIM .GT. -2.) LOLIM =-2
55    PRINT*
      PRINT*,'The plot limits are:'
      PRINT*
      PRINT*,'Octave ', LOFST
      PRINT*,'     to ', OCTAVS
      PRINT*,'     UPPER:', UPLIM
      PRINT*,'     LOWER:', LOLIM
      PRINT*
      PRINT'(1H&,A)','Do you wish to plot using these ? '
      READ'(A1)', REPLY
        IF ((REPLY .NE.'Y') .AND. (REPLY .NE. 'y')) THEN
           PRINT*
           PRINT'(1H&,A)','Enter number of octaves covered: '
           READ*, OCTAVS
           PRINT'(1H&,A)','Enter limits (upper,lower):'
           READ*, UPLIM, LOLIM
           PRINT'(1H&,A)','Now, '
           GOTO 55
        ENDIF
C
C Ghost80 calls
C
100   CALL PAPER (1)
      DO 120 J = 1,PLOT
      IF (J .GT. 1) GOTO 110
       XLO = .05
       XHI = XLO + (OCTAVS  / 20.)
       YLO = .1
       YHI = YLO + ((UPLIM - LOLIM) / 40.)
      CALL PSPACE(XLO, XHI*1.5,YLO*1.5 + .2, YHI*1.5 + .2)
       XLO = LOFST
       XHI = OCTAVS + LOFST - 1
      CALL MAP   (XLO, XHI, LOLIM, UPLIM)
      CALL CTRMAG (10)
       DO 60 K = XLO, XHI
60     CALL PLOTCS(FLOAT(K), -0.35, NMLABL(K))
      CALL MASK(XLO, XHI, -0.5,-.1)
      CALL GRATSI(1.,2.)
      CALL SCALSI(XHI+1.,2.0)
      CALL UNMASK(0)
110   CALL BROKEN (BRARGS(J,1),BRARGS(J,2),
     :             BRARGS(J,3),BRARGS(J,4))
      CALL THICK (3)
      CALL POSITN(FLOAT(FIRST(J)), NMPLOT(J,1))
      DO 120 I = FIRST(J)+1, FIRST(J) + NP(J)
      HI = I - 1
      CALL JOIN  (HI, NMPLOT(J,I-FIRST(J)))
120   CONTINUE
      CALL PSPACE(0.05,0.95,0.05,0.3)
      CALL MAP(0.,1.,0.,1.)
      DO 150 I = 1,PLOT
        CALL THICK (3)
        HI = .05 + (I*.12)
        CALL BROKEN (BRARGS(I,1),BRARGS(I,2),BRARGS(I,3),BRARGS(I,4))
        CALL POSITN(0.,HI)
        CALL JOIN  (.2,HI)
```

```
        CALL THICK(1)
150     CALL PLOTCS(.22,HI,LEGEND(I))
      HI = HI + 0.3
      CALL CTRMAG(25)
      CALL PLOTCS(0.,HI,LABEL)
      CALL GREND
C
C     using   log(D)= log(d) + (n/m)log(2)
C
C             n = m log(D/d) / log(2)
      PRINT*
      PRINT*,'The temporary file "-DAT" contains a copy of the data.'
9000  RETURN
      END
```

1

APPENDIX D

Temperament ratios expressed as decimals with intervals given in cents

EQUAL TEMPERAMENT

CENTS	RATIO
0	1.000000
100	1.059464
200	1.122462
300	1.189207
400	1.259921
500	1.334840
600	1.414213
700	1.498306
800	1.587400
900	1.681792
1000	1.781797
1100	1.887748
1200	2.000000

QUARTER COMMA MEAN TONE

CENTS	RATIO
0	1.000000
76.05	1.044908
193.16	1.118036
310.27	1.196282
386.31	1.249997
503.43	1.337487
579.47	1.397542
696.58	1.495350
772.63	1.562502
889.74	1.671855
1006.85	1.788861
1082.89	1.869184
1200.00	2.000000

FIFTH COMMA MEAN TONE

CENTS	RATIO
0	1.000000
83.58	1.049462
195.31	1.119426
307.04	1.194053
390.61	1.253106
502.35	1.336653
585.92	1.402759
697.65	1.496274
781.23	1.570283
892.96	1.674968
1004.69	1.786631
1088.27	1.875001
1200.00	2.000000

SILBERMANN SIXTH COMMA MEAN TONE

CENTS	RATIO
0	1.000000
86.31	1.051118
196.09	1.119929
305.86	1.193239

392.18	1.254243
501.96	1.336351
588.27	1.404664
698.04	1.496612
784.36	1.573125
894.14	1.676109
1003.91	1.785826
1090.22	1.877114
1200.00	2.000000

WERCKMEISTER III (1691)

0	1.000000
90.23	1.053501
192.18	1.117403
294.14	1.185188
390.23	1.252831
489.04	1.326416
588.27	1.404664
696.09	1.494926
792.18	1.580246
888.27	1.670436
996.09	1.777778
1092.18	1.879240
1200.00	2.000000

KIRNBERGER II (1779)

0	1.000000
90.22	1.053494
203.91	1.125000
294.13	1.185182
386.31	1.249997
498.04	1.333329
590.22	1.406247
701.96	1.500004
792.18	1.580246
895.11	1.677049
996.09	1.777778
1088.27	1.875001
1200.00	2.000000

MODIFIED KIRNBERGER II

0	1.000000
92.22	1.054712
200.00	1.122462
294.14	1.185188
386.31	1.249997
498.04	1.333329
588.27	1.404664
700.00	1.498306
792.18	1.580246
893.16	1.675160
996.09	1.777778
1086.32	1.872890
1200.00	2.000000

KIRNBERGER III

0	1.000000
90.23	1.053501
193.16	1.118036
294.14	1.185188
386.31	1.249997
498.04	1.333329
590.22	1.406247
696.58	1.495350
792.18	1.580246
889.74	1.671855
996.09	1.777778
1088.27	1.875001
1200.00	2.000000

NEIDHART I (1724)

0	1.000000
94.14	1.055883
196.09	1.119929
296.09	1.186524
392.18	1.254243
498.04	1.333329
592.18	1.407840
698.04	1.496612
796.09	1.583819
894.14	1.676109
996.09	1.777778
1092.18	1.879240
1200.00	2.000000

BARNES' PROPOSED J.S. BACH TEMPERAMENT

0	1.000000
94.14	1.055883
196.09	1.119929
298.04	1.187861
392.18	1.254243
501.96	1.336351
592.18	1.407840
698.04	1.496612
796.09	1.583819
894.14	1.676109
1000.00	1.781797
1094.14	1.881370
1200.00	2.000000

KELLNER PROPOSED J.S. BACH TEMPERAMENT

0	1.000000
90.22	1.053494
194.53	1.118921
294.14	1.185188
398.05	1.258503
498.04	1.333329
588.27	1.404664
697.26	1.495937

792.18	1.580246
891.79	1.673836
996.09	1.777778
1091.01	1.877971
1200.00	2.000000

18TH CENTURY ENGLISH 'ORD' TEMPERAMENT

0	1.000000
86.31	1.051118
193.16	1.118036
289.73	1.182173
386.31	1.249997
496.58	1.332206
586.31	1.403074
696.58	1.495350
786.31	1.574898
889.74	1.671855
993.16	1.774771
1086.31	1.872879
1200.00	2.000000

APPROXIMATE FRENCH 18TH CENTURY *TEMPERAMENT ORDINAIRE* (VERSION I)

0	1.000000
89.14	1.052838
194.09	1.118637
293.04	1.184436
388.18	1.251348
502.96	1.337124
587.18	1.403780
697.04	1.495748
791.09	1.579252
891.14	1.673207
998.00	1.779739
1085.22	1.871700
1200.00	2.000000

FRENCH 18TH CENTURY TEMPERAMENT *ORDINAIRE VERSION* II

0	1.000000
86.32	1.051125
196.09	1.119929
292.18	1.183847
392.18	1.254243
498.04	1.333329
588.27	1.404664
698.05	1.496620
788.27	1.576682
894.14	1.676109
996.09	1.777778
1090.23	1.877125
1200.00	2.000000

18TH CENTURY ITALIAN

0	1.000000
84.36	1.049935
192.18	1.117403
288.27	1.181177
384.36	1.248590
496.09	1.331828
584.36	1.401495
696.09	1.494926
784.36	1.573125
888.27	1.670436
992.18	1.773767
1084.36	1.870771
1200.00	2.000000

VALLOTTI (VAN BIEZEN)

0	1.000000
94.14	1.055883
196.09	1.119929
298.04	1.187861
392.18	1.254243
501.96	1.336351
592.18	1.407840
698.04	1.496612
796.09	1.583819
894.14	1.676109
1000.00	1.781797
1090.23	1.877125
1200.00	2.000000

FINCHCOCKS (BYFIELD, 1796)

0	1.000000
97	1.057629
200	1.122462
315	1.199555
400	1.259921
509	1.341797
599	1.413397
701	1.499172
797	1.584652
900	1.681792
1014	1.796264
1099	1.886658
1200.00	2.000000

OAKES PARK (ENGLAND & SON, 1790)

0	1.000000
89	1.052752
198	1.121166
300	1.189207
395	1.256288
498	1.333299
596	1.410950
702	1.500039
792	1.580082
900	1.681792

1002	1.783856
1092	1.879045
1200.00	2.000000

ROYAL TEMPERAMENT (JOHN NORMAN)

0	1.000000
94.14	1.055883
196.09	1.119929
298.04	1.187861
392.18	1.254243
501.96	1.336351
588.27	1.404664
698.04	1.496612
792.18	1.580246
894.14	1.676109
996.09	1.777778
1090.22	1.877114
1200.00	2.000000

PYTHAGOREAN (ARNOUT VAN ZWOLLE, EARLY 15TH CENTURY)

0	1.000000
90.22	1.053494
203.91	1.125000
294.14	1.185188
407.82	1.265625
498.04	1.333329
588.27	1.404664
701.96	1.500004
792.18	1.580246
905.86	1.687495
996.09	1.777778
1109.78	1.898442
1200.00	2.000000

JUST INTONATION

0	1.000000
111.73	1.066666
203.91	1.125000
315.64	1.199999
386.31	1.249997
498.04	1.333329
590.22	1.406247
701.96	1.500004
813.69	1.600003
884.36	1.666668
996.09	1.777778
1088.24	1.874969
1200.00	2.000000

1

APPENDIX E

Test organ pipe-calculations: results given in full

part 1

OPEN DIAPASON 1

Mouth ratio calculated as	3.45455
Ratio of mouth width:diameter	4.38169
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9572
Elliptic function K(e)	0.827
K(e)/0.89	0.929
Pipe Diameter (mm)	53.000
Radius (R2) (mm)	26.500
Mouth width (mm)	38.000
Mouth height (mm)	11.000
Raduis (R1) (mm)	11.535
Frequency (Hz)	262.000
Wave number	0.00481
Plate width (mm)	166.504
Half-plate width (mm)	83.252
Cross-sectional area (sq. mm)	8824.734
Open end correction (.6133r) (mm)	16.252
L1 (mm)	251.240
Effective length (mm)	653.737
COT(KL)	73.511
L 2 (mm)	256.206
Computed length (mm)	566.822

OPEN DIAPASON 2

Mouth ratio calculated as	3.50000
Ratio of mouth width:diameter	4.26359
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9583
Elliptic function K(e)	0.832
K(e)/0.89	0.935
Pipe Diameter (mm)	28.500
Radius (R2) (mm)	14.250
Mouth width (mm)	21.000
Mouth height (mm)	6.000
Raduis (R1) (mm)	6.333
Frequency (Hz)	527.900
Wave number	0.00968
Plate width (mm)	89.535
Half-plate width (mm)	44.768
Cross-sectional area (sq. mm)	2551.759
Open end correction (.6133r) (mm)	8.740
L1 (mm)	122.609
Effective length (mm)	324.454
COT(KL)	38.968
L 2 (mm)	124.964
Computed length (mm)	278.452

OPEN DIAPASON 3

Mouth ratio calculated as	3.50000
Ratio of mouth width:diameter	4.12895
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9583
Elliptic function K(e)	0.832
K(e)/0.89	0.935
Pipe Diameter (mm)	23.000
Radius (R2) (mm)	11.500
Mouth width (mm)	17.500
Mouth height (mm)	5.000
Raduis (R1) (mm)	5.278
Frequency (Hz)	785.800
Wave number	0.01441
Plate width (mm)	72.257
Half-plate width (mm)	36.128
Cross-sectional area (sq. mm)	1661.903
Open end correction (.6133r) (mm)	7.053
L1 (mm)	78.527
Effective length (mm)	217.968
COT(KL)	30.455
L 2 (mm)	80.286
Computed length (mm)	182.217

OPEN DIAPASON 4

Mouth ratio calculated as	3.12500
Ratio of mouth width:diameter	4.39823
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9474
Elliptic function K(e)	0.788
K(e)/0.89	0.886
Pipe Diameter (mm)	21.000
Radius (R2) (mm)	10.500
Mouth width (mm)	15.000
Mouth height (mm)	4.800
Raduis (R1) (mm)	4.787
Frequency (Hz)	818.100
Wave number	0.01501
Plate width (mm)	65.973
Half-plate width (mm)	32.987
Cross-sectional area (sq. mm)	1385.442
Open end correction (.6133r) (mm)	6.440
L1 (mm)	76.543
Effective length (mm)	209.362
COT(KL)	26.511
L 2 (mm)	79.449
Computed length (mm)	177.690

OPEN DIAPASON 5

Mouth ratio calculated as	3.50000
Ratio of mouth width:diameter	4.26359
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839

Eccentricity of ellipse (e)	0.9583
Elliptic function K(e)	0.832
K(e)/0.89	0.935
Pipe Diameter (mm)	19.000
Radius (R2) (mm)	9.500
Mouth width (mm)	14.000
Mouth height (mm)	4.000
Raduis (R1) (mm)	4.222
Frequency (Hz)	1058.800
Wave number	0.01942
Plate width (mm)	59.690
Half-plate width (mm)	29.845
Cross-sectional area (sq. mm)	1134.115
Open end correction (.6133r) (mm)	5.826
L1 (mm)	55.401
Effective length (mm)	161.767
COT(KL)	25.979
L 2 (mm)	56.823
Computed length (mm)	131.881

OPEN DIAPASON 6

Mouth ratio calculated as	3.33333
Ratio of mouth width:diameter	4.10824
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9539
Elliptic function K(e)	0.812
K(e)/0.89	0.913
Pipe Diameter (mm)	17.000
Radius (R2) (mm)	8.500
Mouth width (mm)	13.000
Mouth height (mm)	3.900
Raduis (R1) (mm)	4.017
Frequency (Hz)	1314.100
Wave number	0.02410
Plate width (mm)	53.407
Half-plate width (mm)	26.704
Cross-sectional area (sq. mm)	907.920
Open end correction (.6133r) (mm)	5.213
L1 (mm)	43.879
Effective length (mm)	130.340
COT(KL)	21.340
L 2 (mm)	45.460
Computed length (mm)	105.416

OPEN DIAPASON 7

Mouth ratio calculated as	3.39394
Ratio of mouth width:diameter	4.15139
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9556
Elliptic function K(e)	0.819
K(e)/0.89	0.921
Pipe Diameter (mm)	14.800

Radius (R2) (mm)	7.400
Mouth width (mm)	11.200
Mouth height (mm)	3.300
Raduis (R1) (mm)	3.430
Frequency (Hz)	1596.600
Wave number	0.02928
Plate width (mm)	46.496
Half-plate width (mm)	23.248
Cross-sectional area (sq. mm)	688.135
Open end correction (.6133r) (mm)	4.538
L1 (mm)	34.990
Effective length (mm)	107.277
COT(KL)	19.110
L 2 (mm)	36.216
Computed length (mm)	85.317

OPEN DIAPASON 8

Mouth ratio calculated as	4.09091
Ratio of mouth width:diameter	3.80482
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9697
Elliptic function K(e)	0.902
K(e)/0.89	1.014
Pipe Diameter (mm)	10.900
Radius (R2) (mm)	5.450
Mouth width (mm)	9.000
Mouth height (mm)	2.200
Raduis (R1) (mm)	2.510
Frequency (Hz)	2131.200
Wave number	0.03909
Plate width (mm)	34.243
Half-plate width (mm)	17.122
Cross-sectional area (sq. mm)	373.252
Open end correction (.6133r) (mm)	3.342
L1 (mm)	26.336
Effective length (mm)	80.367
COT(KL)	15.596
L 2 (mm)	26.178
Computed length (mm)	63.019

BLOCKFLUTE

Mouth ratio calculated as	3.21138
Ratio of mouth width:diameter	5.19357
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9503
Elliptic function K(e)	0.798
K(e)/0.89	0.897
Pipe Diameter (mm)	65.300
Radius (R2) (mm)	32.650
Mouth width (mm)	39.500
Mouth height (mm)	12.300
Raduis (R1) (mm)	12.436

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Frequency (Hz)	260.700
Wave number	0.00478
Plate width (mm)	205.146
Half-plate width (mm)	102.573
Cross-sectional area (sq. mm)	13396.035
Open end correction (.6133r) (mm)	20.024
L1 (mm)	226.110
Effective length (mm)	656.997
COT(KL)	99.931
L 2 (mm)	235.276
Computed length (mm)	543.751

SALICIONAL

Mouth ratio calculated as	3.01429
Ratio of mouth width:diameter	4.51139
Temperature in degrees K	291.94971
Speed of sound (m per sec)	342.55839
Eccentricity of ellipse (e)	0.9434
Elliptic function K(e)	0.776
K(e)/0.89	0.871
Pipe Diameter (mm)	30.300
Radius (R2) (mm)	15.150
Mouth width (mm)	21.100
Mouth height (mm)	7.000
Raduis (R1) (mm)	6.857
Frequency (Hz)	265.000
Wave number	0.00486
Plate width (mm)	95.190
Half-plate width (mm)	47.595
Cross-sectional area (sq. mm)	2884.265
Open end correction (.6133r) (mm)	9.291
L1 (mm)	280.284
Effective length (mm)	646.337
COT(KL)	37.918
L 2 (mm)	285.671
Computed length (mm)	599.547

College of St Hild & St. Bede; Pedal Principal 8' extension: pipe-calculations in full

Part 2

CC pipe 1

Mouth ratio calculated as	3.45614
Ratio of mouth width:diameter	4.17551
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9572
Elliptic function K(e)	0.827
K(e)/0.89	0.929
Pipe Diameter (mm)	130.917
Radius (R2) (mm)	65.459
Mouth width (mm)	98.500
Mouth height (mm)	28.500
Raduis (R1) (mm)	29.893
Frequency (Hz)	65.408
Wave number	0.00122
Plate width (mm)	411.288
Half-plate width (mm)	205.644
Cross-sectional area (sq. mm)	53844.578
Open end correction (.6133r) (mm)	40.146
L1 (mm)	1108.468
Effective length (mm)	2583.430
COT(KL)	173.116
L 2 (mm)	1121.091
Computed length (mm)	2372.660

CC# pipe 2

Mouth ratio calculated as	3.45614
Ratio of mouth width:diameter	4.17551
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9572
Elliptic function K(e)	0.827
K(e)/0.89	0.929
Pipe Diameter (mm)	130.917
Radius (R2) (mm)	65.459
Mouth width (mm)	98.500
Mouth height (mm)	28.500
Raduis (R1) (mm)	29.893
Frequency (Hz)	69.297
Wave number	0.00129
Plate width (mm)	411.288
Half-plate width (mm)	205.644
Cross-sectional area (sq. mm)	53844.578
Open end correction (.6133r) (mm)	40.146
L1 (mm)	1036.337
Effective length (mm)	2438.435
COT(KL)	173.116
L 2 (mm)	1048.889
Computed length (mm)	2227.961

DD pipe 3

Mouth ratio calculated as	3.38461
Ratio of mouth width:diameter	4.23055

Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9554
Elliptic function K(e)	0.818
K(e)/0.89	0.920
Pipe Diameter (mm)	118.503
Radius (R2) (mm)	59.252
Mouth width (mm)	88.000
Mouth height (mm)	26.000
Raduis (R1) (mm)	26.987
Frequency (Hz)	73.417
Wave number	0.00136
Plate width (mm)	372.288
Half-plate width (mm)	186.144
Cross-sectional area (sq. mm)	44117.266
Open end correction (.6133r) (mm)	36.339
L1 (mm)	984.582
Effective length (mm)	2301.577
COT(KL)	155.508
L 2 (mm)	997.554
Computed length (mm)	2112.004

DD# pipe 4

Mouth ratio calculated as	3.38461
Ratio of mouth width:diameter	4.23055
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9554
Elliptic function K(e)	0.818
K(e)/0.89	0.920
Pipe Diameter (mm)	118.503
Radius (R2) (mm)	59.252
Mouth width (mm)	88.000
Mouth height (mm)	26.000
Raduis (R1) (mm)	26.987
Frequency (Hz)	77.783
Wave number	0.00145
Plate width (mm)	372.288
Half-plate width (mm)	186.144
Cross-sectional area (sq. mm)	44117.266
Open end correction (.6133r) (mm)	36.339
L1 (mm)	920.338
Effective length (mm)	2172.401
COT(KL)	155.508
L 2 (mm)	933.237
Computed length (mm)	1983.098

EE pipe 5

Mouth ratio calculated as	3.45652
Ratio of mouth width:diameter	4.23005
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9572
Elliptic function K(e)	0.827
K(e)/0.89	0.929
Pipe Diameter (mm)	107.044

Radius (R2) (mm)	53.522
Mouth width (mm)	79.500
Mouth height (mm)	23.000
Raduis (R1) (mm)	24.125
Frequency (Hz)	82.408
Wave number	0.00153
Plate width (mm)	336.289
Half-plate width (mm)	168.144
Cross-sectional area (sq. mm)	35997.684
Open end correction (.6133r) (mm)	32.825
L1 (mm)	873.662
Effective length (mm)	2050.474
COT(KL)	143.412
L 2 (mm)	884.068
Computed length (mm)	1876.480

FF pipe 6

Mouth ratio calculated as	3.40400
Ratio of mouth width:diameter	4.20361
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9559
Elliptic function K(e)	0.821
K(e)/0.89	0.922
Pipe Diameter (mm)	107.044
Radius (R2) (mm)	53.522
Mouth width (mm)	80.000
Mouth height (mm)	23.502
Raduis (R1) (mm)	24.464
Frequency (Hz)	87.308
Wave number	0.00162
Plate width (mm)	336.289
Half-plate width (mm)	168.144
Cross-sectional area (sq. mm)	35997.684
Open end correction (.6133r) (mm)	32.825
L1 (mm)	818.459
Effective length (mm)	1935.391
COT(KL)	140.367
L 2 (mm)	829.685
Computed length (mm)	1764.555

FF# pipe 7

Mouth ratio calculated as	3.37209
Ratio of mouth width:diameter	4.22226
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9550
Elliptic function K(e)	0.817
K(e)/0.89	0.918
Pipe Diameter (mm)	97.439
Radius (R2) (mm)	48.720
Mouth width (mm)	72.500
Mouth height (mm)	21.500
Raduis (R1) (mm)	22.275
Frequency (Hz)	92.500
Wave number	0.00172

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Plate width (mm)	306.114
Half-plate width (mm)	153.057
Cross-sectional area (sq. mm)	29827.410
Open end correction (.6133r) (mm)	29.880
L1 (mm)	777.391
Effective length (mm)	1826.767
COT(KL)	127.150
L 2 (mm)	788.204
Computed length (mm)	1671.707

GG pipe 8

Mouth ratio calculated as	3.22700
Ratio of mouth width:diameter	4.31146
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9508
Elliptic function K(e)	0.800
K(e)/0.89	0.899
Pipe Diameter (mm)	97.439
Radius (R2) (mm)	48.720
Mouth width (mm)	71.000
Mouth height (mm)	22.002
Raduis (R1) (mm)	22.299
Frequency (Hz)	98.000
Wave number	0.00182
Plate width (mm)	306.114
Half-plate width (mm)	153.057
Cross-sectional area (sq. mm)	29827.410
Open end correction (.6133r) (mm)	29.880
L1 (mm)	726.567
Effective length (mm)	1724.239
COT(KL)	124.371
L 2 (mm)	739.815
Computed length (mm)	1572.054

GG# pipe 9

Mouth ratio calculated as	3.35000
Ratio of mouth width:diameter	4.15356
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9544
Elliptic function K(e)	0.814
K(e)/0.89	0.915
Pipe Diameter (mm)	88.582
Radius (R2) (mm)	44.291
Mouth width (mm)	67.000
Mouth height (mm)	20.000
Raduis (R1) (mm)	20.653
Frequency (Hz)	103.828
Wave number	0.00193
Plate width (mm)	278.289
Half-plate width (mm)	139.144
Cross-sectional area (sq. mm)	24651.359
Open end correction (.6133r) (mm)	27.164
L1 (mm)	692.515
Effective length (mm)	1627.466

COT(KL)	112.978
L 2 (mm)	702.497
Computed length (mm)	1489.066

AA pipe 10

Mouth ratio calculated as	3.17100
Ratio of mouth width:diameter	4.28136
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9490
Elliptic function K(e)	0.793
K(e)/0.89	0.891
Pipe Diameter (mm)	88.582
Radius (R2) (mm)	44.291
Mouth width (mm)	65.000
Mouth height (mm)	20.498
Raduis (R1) (mm)	20.594
Frequency (Hz)	110.001
Wave number	0.00205
Plate width (mm)	278.289
Half-plate width (mm)	139.144
Cross-sectional area (sq. mm)	24651.359
Open end correction (.6133r) (mm)	27.164
L1 (mm)	646.780
Effective length (mm)	1536.124
COT(KL)	110.394
L 2 (mm)	659.488
Computed length (mm)	1400.386

AA# pipe 11

Mouth ratio calculated as	3.33300
Ratio of mouth width:diameter	4.13643
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9539
Elliptic function K(e)	0.812
K(e)/0.89	0.913
Pipe Diameter (mm)	79.000
Radius (R2) (mm)	39.500
Mouth width (mm)	60.000
Mouth height (mm)	18.002
Raduis (R1) (mm)	18.542
Frequency (Hz)	116.542
Wave number	0.00217
Plate width (mm)	248.186
Half-plate width (mm)	124.093
Cross-sectional area (sq. mm)	19606.680
Open end correction (.6133r) (mm)	24.225
L1 (mm)	617.546
Effective length (mm)	1449.909
COT(KL)	99.841
L 2 (mm)	626.629
Computed length (mm)	1327.358

BB pipe 12

Mouth ratio calculated as	3.37100
Ratio of mouth width:diameter	4.20654
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9550
Elliptic function K(e)	0.817
K(e)/0.89	0.918
Pipe Diameter (mm)	79.000
Radius (R2) (mm)	39.500
Mouth width (mm)	59.000
Mouth height (mm)	17.502
Raduis (R1) (mm)	18.130
Frequency (Hz)	123.472
Wave number	0.00230
Plate width (mm)	248.186
Half-plate width (mm)	124.093
Cross-sectional area (sq. mm)	19606.680
Open end correction (.6133r) (mm)	24.225
L1 (mm)	574.756
Effective length (mm)	1368.532
COT(KL)	102.672
L 2 (mm)	583.434
Computed length (mm)	1243.475

C pipe 13

Mouth ratio calculated as	3.37100
Ratio of mouth width:diameter	4.05100
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9550
Elliptic function K(e)	0.817
K(e)/0.89	0.918
Pipe Diameter (mm)	73.500
Radius (R2) (mm)	36.750
Mouth width (mm)	57.000
Mouth height (mm)	16.909
Raduis (R1) (mm)	17.515
Frequency (Hz)	130.814
Wave number	0.00243
Plate width (mm)	230.907
Half-plate width (mm)	115.454
Cross-sectional area (sq. mm)	16971.668
Open end correction (.6133r) (mm)	22.539
L1 (mm)	547.540
Effective length (mm)	1291.723
COT(KL)	91.992
L 2 (mm)	555.360
Computed length (mm)	1178.683

C# pipe 14

Mouth ratio calculated as	3.37500
Ratio of mouth width:diameter	4.27606
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9551
Elliptic function K(e)	0.817

K(e)/0.89	0.918
Pipe Diameter (mm)	73.500
Radius (R2) (mm)	36.750
Mouth width (mm)	54.000
Mouth height (mm)	16.000
Raduis (R1) (mm)	16.584
Frequency (Hz)	138.593
Wave number	0.00258
Plate width (mm)	230.907
Half-plate width (mm)	115.454
Cross-sectional area (sq. mm)	16971.668
Open end correction (.6133r) (mm)	22.539
L1 (mm)	506.257
Effective length (mm)	1219.225
COT(KL)	97.216
L 2 (mm)	514.356
Computed length (mm)	1101.430

D pipe 15

Mouth ratio calculated as	3.16100
Ratio of mouth width:diameter	4.26359
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9486
Elliptic function K(e)	0.792
K(e)/0.89	0.890
Pipe Diameter (mm)	66.500
Radius (R2) (mm)	33.250
Mouth width (mm)	49.000
Mouth height (mm)	15.501
Raduis (R1) (mm)	15.549
Frequency (Hz)	146.834
Wave number	0.00273
Plate width (mm)	208.916
Half-plate width (mm)	104.458
Cross-sectional area (sq. mm)	13892.906
Open end correction (.6133r) (mm)	20.392
L1 (mm)	484.857
Effective length (mm)	1150.796
COT(KL)	82.281
L 2 (mm)	494.461
Computed length (mm)	1049.466

D# pipe 16

Mouth ratio calculated as	3.40000
Ratio of mouth width:diameter	4.09639
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9558
Elliptic function K(e)	0.820
K(e)/0.89	0.922
Pipe Diameter (mm)	66.500
Radius (R2) (mm)	33.250
Mouth width (mm)	51.000
Mouth height (mm)	15.000
Raduis (R1) (mm)	15.605

1

Frequency (Hz)	155.565
Wave number	0.00289
Plate width (mm)	208.916
Half-plate width (mm)	104.458
Cross-sectional area (sq. mm)	13892.906
Open end correction (.6133r) (mm)	20.392
L1 (mm)	453.091
Effective length (mm)	1086.207
COT(KL)	84.879
L 2 (mm)	459.871
Computed length (mm)	982.582

E pipe 17

Mouth ratio calculated as	3.17241
Ratio of mouth width:diameter	4.24115
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9490
Elliptic function K(e)	0.794
K(e)/0.89	0.892
Pipe Diameter (mm)	62.100
Radius (R2) (mm)	31.050
Mouth width (mm)	46.000
Mouth height (mm)	14.500
Raduis (R1) (mm)	14.571
Frequency (Hz)	164.815
Wave number	0.00306
Plate width (mm)	195.093
Half-plate width (mm)	97.546
Cross-sectional area (sq. mm)	12115.270
Open end correction (.6133r) (mm)	19.043
L1 (mm)	428.519
Effective length (mm)	1025.243
COT(KL)	76.697
L 2 (mm)	437.291
Computed length (mm)	930.870

F pipe 18

Mouth ratio calculated as	2.93333
Ratio of mouth width:diameter	4.23401
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9401
Elliptic function K(e)	0.766
K(e)/0.89	0.861
Pipe Diameter (mm)	59.300
Radius (R2) (mm)	29.650
Mouth width (mm)	44.000
Mouth height (mm)	15.000
Raduis (R1) (mm)	14.494
Frequency (Hz)	174.616
Wave number	0.00325
Plate width (mm)	186.296
Half-plate width (mm)	93.148
Cross-sectional area (sq. mm)	11047.379
Open end correction (.6133r) (mm)	18.184

L1 (mm)	406.659
Effective length (mm)	967.701
COT(KL)	67.903
L 2 (mm)	417.017
Computed length (mm)	882.683

F# pipe 19

Mouth ratio calculated as	2.92857
Ratio of mouth width:diameter	4.29862
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9399
Elliptic function K(e)	0.766
K(e)/0.89	0.861
Pipe Diameter (mm)	56.100
Radius (R2) (mm)	28.050
Mouth width (mm)	41.000
Mouth height (mm)	14.000
Raduis (R1) (mm)	13.517
Frequency (Hz)	184.999
Wave number	0.00344
Plate width (mm)	176.243
Half-plate width (mm)	88.122
Cross-sectional area (sq. mm)	9887.250
Open end correction (.6133r) (mm)	17.203
L1 (mm)	382.666
Effective length (mm)	913.389
COT(KL)	65.121
L 2 (mm)	392.631
Computed length (mm)	832.122

G pipe 20

Mouth ratio calculated as	2.81481
Ratio of mouth width:diameter	4.45610
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9348
Elliptic function K(e)	0.753
K(e)/0.89	0.847
Pipe Diameter (mm)	53.900
Radius (R2) (mm)	26.950
Mouth width (mm)	38.000
Mouth height (mm)	13.500
Raduis (R1) (mm)	12.779
Frequency (Hz)	195.999
Wave number	0.00364
Plate width (mm)	169.332
Half-plate width (mm)	84.666
Cross-sectional area (sq. mm)	9126.984
Open end correction (.6133r) (mm)	16.528
L1 (mm)	358.886
Effective length (mm)	862.125
COT(KL)	62.555
L 2 (mm)	369.559
Computed length (mm)	784.093

G# pipe 21

Mouth ratio calculated as	2.84600
Ratio of mouth width:diameter	4.32181
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9362
Elliptic function K(e)	0.757
K(e)/0.89	0.850
Pipe Diameter (mm)	50.900
Radius (R2) (mm)	25.450
Mouth width (mm)	37.000
Mouth height (mm)	13.001
Raduis (R1) (mm)	12.374
Frequency (Hz)	207.654
Wave number	0.00386
Plate width (mm)	159.907
Half-plate width (mm)	79.954
Cross-sectional area (sq. mm)	8139.270
Open end correction (.6133r) (mm)	15.608
L1 (mm)	340.325
Effective length (mm)	813.738
COT(KL)	57.867
L 2 (mm)	349.937
Computed length (mm)	741.197

A pipe 22

Mouth ratio calculated as	2.88000
Ratio of mouth width:diameter	4.36332
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9378
Elliptic function K(e)	0.761
K(e)/0.89	0.855
Pipe Diameter (mm)	50.000
Radius (R2) (mm)	25.000
Mouth width (mm)	36.000
Mouth height (mm)	12.500
Raduis (R1) (mm)	11.968
Frequency (Hz)	220.001
Wave number	0.00409
Plate width (mm)	157.080
Half-plate width (mm)	78.540
Cross-sectional area (sq. mm)	7853.980
Open end correction (.6133r) (mm)	15.333
L1 (mm)	317.814
Effective length (mm)	768.067
COT(KL)	58.015
L 2 (mm)	327.072
Computed length (mm)	695.773

A# pipe 23

Mouth ratio calculated as	2.83300
Ratio of mouth width:diameter	4.48139
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147

Eccentricity of ellipse (e)	0.9356
Elliptic function K(e)	0.755
K(e)/0.89	0.849
Pipe Diameter (mm)	48.500
Radius (R2) (mm)	24.250
Mouth width (mm)	34.000
Mouth height (mm)	12.001
Raduis (R1) (mm)	11.397
Frequency (Hz)	233.083
Wave number	0.00433
Plate width (mm)	152.367
Half-plate width (mm)	76.184
Cross-sectional area (sq. mm)	7389.809
Open end correction (.6133r) (mm)	14.873
L1 (mm)	297.199
Effective length (mm)	724.959
COT(KL)	56.938
L 2 (mm)	306.657
Computed length (mm)	654.264

B pipe 24

Mouth ratio calculated as	2.87000
Ratio of mouth width:diameter	4.28399
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9373
Elliptic function K(e)	0.759
K(e)/0.89	0.853
Pipe Diameter (mm)	45.000
Radius (R2) (mm)	22.500
Mouth width (mm)	33.000
Mouth height (mm)	11.498
Raduis (R1) (mm)	10.990
Frequency (Hz)	246.943
Wave number	0.00459
Plate width (mm)	141.372
Half-plate width (mm)	70.686
Cross-sectional area (sq. mm)	6361.723
Open end correction (.6133r) (mm)	13.799
L1 (mm)	283.695
Effective length (mm)	684.270
COT(KL)	51.101
L 2 (mm)	291.942
Computed length (mm)	620.278

c pipe 25

Mouth ratio calculated as	2.81800
Ratio of mouth width:diameter	4.25635
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9349
Elliptic function K(e)	0.754
K(e)/0.89	0.847
Pipe Diameter (mm)	42.000
Radius (R2) (mm)	21.000
Mouth width (mm)	31.000

1 Mouth height (mm)	11.001
Raduis (R1) (mm)	10.419
Frequency (Hz)	261.627
Wave number	0.00486
Plate width (mm)	131.947
Half-plate width (mm)	65.973
Cross-sectional area (sq. mm)	5541.770
Open end correction (.6133r) (mm)	12.879
L1 (mm)	269.167
Effective length (mm)	645.866
COT(KL)	46.606
L 2 (mm)	277.101
Computed length (mm)	587.154

c# pipe 26

Mouth ratio calculated as	2.66700
Ratio of mouth width:diameter	4.48799
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9270
Elliptic function K(e)	0.738
K(e)/0.89	0.829
Pipe Diameter (mm)	40.000
Radius (R2) (mm)	20.000
Mouth width (mm)	28.000
Mouth height (mm)	10.499
Raduis (R1) (mm)	9.673
Frequency (Hz)	277.184
Wave number	0.00515
Plate width (mm)	125.664
Half-plate width (mm)	62.832
Cross-sectional area (sq. mm)	5026.547
Open end correction (.6133r) (mm)	12.266
L1 (mm)	252.367
Effective length (mm)	609.616
COT(KL)	44.574
L 2 (mm)	260.995
Computed length (mm)	553.537

d pipe 27

Mouth ratio calculated as	2.75000
Ratio of mouth width:diameter	4.34111
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9315
Elliptic function K(e)	0.747
K(e)/0.89	0.839
Pipe Diameter (mm)	38.000
Radius (R2) (mm)	19.000
Mouth width (mm)	27.500
Mouth height (mm)	10.000
Raduis (R1) (mm)	9.356
Frequency (Hz)	293.666
Wave number	0.00546
Plate width (mm)	119.381
Half-plate width (mm)	59.690

1 Cross-sectional area (sq. mm)	4536.457
Open end correction (.6133r) (mm)	11.653
L1 (mm)	238.741
Effective length (mm)	575.401
COT(KL)	42.077
L 2 (mm)	246.341
Computed length (mm)	522.389

d# pipe 28

Mouth ratio calculated as	2.60000
Ratio of mouth width:diameter	4.47073
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9231
Elliptic function K(e)	0.731
K(e)/0.89	0.822
Pipe Diameter (mm)	37.000
Radius (R2) (mm)	18.500
Mouth width (mm)	26.000
Mouth height (mm)	10.000
Raduis (R1) (mm)	9.097
Frequency (Hz)	311.128
Wave number	0.00578
Plate width (mm)	116.239
Half-plate width (mm)	58.119
Cross-sectional area (sq. mm)	4300.840
Open end correction (.6133r) (mm)	11.346
L1 (mm)	223.891
Effective length (mm)	543.107
COT(KL)	40.183
L 2 (mm)	232.072
Computed length (mm)	492.279

e pipe 29

Mouth ratio calculated as	2.60000
Ratio of mouth width:diameter	4.41031
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9231
Elliptic function K(e)	0.731
K(e)/0.89	0.822
Pipe Diameter (mm)	36.500
Radius (R2) (mm)	18.250
Mouth width (mm)	26.000
Mouth height (mm)	10.000
Raduis (R1) (mm)	9.097
Frequency (Hz)	329.628
Wave number	0.00613
Plate width (mm)	114.668
Half-plate width (mm)	57.334
Cross-sectional area (sq. mm)	4185.387
Open end correction (.6133r) (mm)	11.193
L1 (mm)	210.003
Effective length (mm)	512.625
COT(KL)	39.104
L 2 (mm)	217.932

1 Computed length (mm)	463.052

f pipe 30

Mouth ratio calculated as	2.73700
Ratio of mouth width:diameter	4.10824
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9309
Elliptic function K(e)	0.745
K(e)/0.89	0.837
Pipe Diameter (mm)	34.000
Radius (R2) (mm)	17.000
Mouth width (mm)	26.000
Mouth height (mm)	9.499
Raduis (R1) (mm)	8.867
Frequency (Hz)	349.229
Wave number	0.00649
Plate width (mm)	106.814
Half-plate width (mm)	53.407
Cross-sectional area (sq. mm)	3631.681
Open end correction (.6133r) (mm)	10.426
L1 (mm)	200.578
Effective length (mm)	483.854
COT(KL)	35.479
L 2 (mm)	207.056
Computed length (mm)	438.557

f# pipe 31

Mouth ratio calculated as	2.66700
Ratio of mouth width:diameter	4.31969
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9270
Elliptic function K(e)	0.738
K(e)/0.89	0.829
Pipe Diameter (mm)	33.000
Radius (R2) (mm)	16.500
Mouth width (mm)	24.000
Mouth height (mm)	8.999
Raduis (R1) (mm)	8.291
Frequency (Hz)	369.995
Wave number	0.00688
Plate width (mm)	103.673
Half-plate width (mm)	51.836
Cross-sectional area (sq. mm)	3421.195
Open end correction (.6133r) (mm)	10.119
L1 (mm)	186.830
Effective length (mm)	456.697
COT(KL)	35.394
L 2 (mm)	193.630
Computed length (mm)	411.859

g pipe 32

Mouth ratio calculated as	2.61400
Ratio of mouth width:diameter	4.37091

Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9239
Elliptic function K(e)	0.733
K(e)/0.89	0.823
Pipe Diameter (mm)	32.000
Radius (R2) (mm)	16.000
Mouth width (mm)	23.000
Mouth height (mm)	8.799
Raduis (R1) (mm)	8.026
Frequency (Hz)	391.996
Wave number	0.00729
Plate width (mm)	100.531
Half-plate width (mm)	50.265
Cross-sectional area (sq. mm)	3216.991
Open end correction (.6133r) (mm)	9.813
L1 (mm)	175.265
Effective length (mm)	431.065
COT(KL)	34.133
L 2 (mm)	182.079
Computed length (mm)	387.798

g# pipe 33

Mouth ratio calculated as	2.64700
Ratio of mouth width:diameter	4.32842
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9259
Elliptic function K(e)	0.736
K(e)/0.89	0.827
Pipe Diameter (mm)	31.000
Radius (R2) (mm)	15.500
Mouth width (mm)	22.500
Mouth height (mm)	8.500
Raduis (R1) (mm)	7.802
Frequency (Hz)	415.305
Wave number	0.00772
Plate width (mm)	97.389
Half-plate width (mm)	48.695
Cross-sectional area (sq. mm)	3019.071
Open end correction (.6133r) (mm)	9.506
L1 (mm)	164.613
Effective length (mm)	406.872
COT(KL)	33.100
L 2 (mm)	171.030
Computed length (mm)	364.959

a pipe 34

Mouth ratio calculated as	2.68800
Ratio of mouth width:diameter	4.38362
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9282
Elliptic function K(e)	0.740
K(e)/0.89	0.832
Pipe Diameter (mm)	30.000

1 Radius (R2) (mm)	15.000
Mouth width (mm)	21.500
Mouth height (mm)	7.999
Raduis (R1) (mm)	7.399
Frequency (Hz)	440.000
Wave number	0.00818
Plate width (mm)	94.248
Half-plate width (mm)	47.124
Cross-sectional area (sq. mm)	2827.434
Open end correction (.6133r) (mm)	9.200
L1 (mm)	153.781
Effective length (mm)	384.036
COT(KL)	32.877
L 2 (mm)	159.901
Computed length (mm)	342.720

a# pipe 35

Mouth ratio calculated as	2.37500
Ratio of mouth width:diameter	4.62972
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9070
Elliptic function K(e)	0.710
K(e)/0.89	0.798
Pipe Diameter (mm)	28.000
Radius (R2) (mm)	14.000
Mouth width (mm)	19.000
Mouth height (mm)	8.000
Raduis (R1) (mm)	6.956
Frequency (Hz)	466.164
Wave number	0.00867
Plate width (mm)	87.965
Half-plate width (mm)	43.982
Cross-sectional area (sq. mm)	2463.009
Open end correction (.6133r) (mm)	8.586
L1 (mm)	145.771
Effective length (mm)	362.482
COT(KL)	29.243
L 2 (mm)	152.601
Computed length (mm)	325.256

b pipe 36

Mouth ratio calculated as	2.53300
Ratio of mouth width:diameter	4.46437
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9188
Elliptic function K(e)	0.725
K(e)/0.89	0.814
Pipe Diameter (mm)	27.000
Radius (R2) (mm)	13.500
Mouth width (mm)	19.000
Mouth height (mm)	7.501
Raduis (R1) (mm)	6.735
Frequency (Hz)	493.883
Wave number	0.00918

Plate width (mm)	84.823
Half-plate width (mm)	42.411
Cross-sectional area (sq. mm)	2290.221
Open end correction (.6133r) (mm)	8.280
L1 (mm)	137.044
Effective length (mm)	342.137
COT(KL)	28.644
L 2 (mm)	143.059
Computed length (mm)	305.848

cl pipe 37

Mouth ratio calculated as	2.64286
Ratio of mouth width:diameter	4.41521
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9257
Elliptic function K(e)	0.736
K(e)/0.89	0.826
Pipe Diameter (mm)	26.000
Radius (R2) (mm)	13.000
Mouth width (mm)	18.500
Mouth height (mm)	7.000
Raduis (R1) (mm)	6.420
Frequency (Hz)	523.250
Wave number	0.00973
Plate width (mm)	81.681
Half-plate width (mm)	40.841
Cross-sectional area (sq. mm)	2123.717
Open end correction (.6133r) (mm)	7.973
L1 (mm)	128.434
Effective length (mm)	322.935
COT(KL)	28.279
L 2 (mm)	133.871
Computed length (mm)	287.365

c#1 pipe 38

Mouth ratio calculated as	2.76900
Ratio of mouth width:diameter	4.18879
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9325
Elliptic function K(e)	0.749
K(e)/0.89	0.841
Pipe Diameter (mm)	24.000
Radius (R2) (mm)	12.000
Mouth width (mm)	18.000
Mouth height (mm)	6.501
Raduis (R1) (mm)	6.103
Frequency (Hz)	554.364
Wave number	0.01031
Plate width (mm)	75.398
Half-plate width (mm)	37.699
Cross-sectional area (sq. mm)	1809.557
Open end correction (.6133r) (mm)	7.360
L1 (mm)	122.696
Effective length (mm)	304.810

COT(KL)	25.800
L 2 (mm)	127.188
Computed length (mm)	272.234

dl pipe 39

Mouth ratio calculated as	2.61500
Ratio of mouth width:diameter	4.34279
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9240
Elliptic function K(e)	0.733
K(e)/0.89	0.823
Pipe Diameter (mm)	23.500
Radius (R2) (mm)	11.750
Mouth width (mm)	17.000
Mouth height (mm)	6.501
Raduis (R1) (mm)	5.931
Frequency (Hz)	587.328
Wave number	0.01092
Plate width (mm)	73.827
Half-plate width (mm)	36.914
Cross-sectional area (sq. mm)	1734.945
Open end correction (.6133r) (mm)	7.206
L1 (mm)	114.625
Effective length (mm)	287.702
COT(KL)	24.913
L 2 (mm)	119.527
Computed length (mm)	256.172

d#1 pipe 40

Mouth ratio calculated as	2.53800
Ratio of mouth width:diameter	4.47439
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9191
Elliptic function K(e)	0.725
K(e)/0.89	0.815
Pipe Diameter (mm)	23.500
Radius (R2) (mm)	11.750
Mouth width (mm)	16.500
Mouth height (mm)	6.501
Raduis (R1) (mm)	5.843
Frequency (Hz)	622.252
Wave number	0.01157
Plate width (mm)	73.827
Half-plate width (mm)	36.914
Cross-sectional area (sq. mm)	1734.945
Open end correction (.6133r) (mm)	7.206
L1 (mm)	106.265
Effective length (mm)	271.555
COT(KL)	25.028
L 2 (mm)	111.416
Computed length (mm)	239.987

el pipe 41

Mouth ratio calculated as	2.75000
Ratio of mouth width:diameter	4.37919
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9315
Elliptic function K(e)	0.747
K(e)/0.89	0.839
Pipe Diameter (mm)	23.000
Radius (R2) (mm)	11.500
Mouth width (mm)	16.500
Mouth height (mm)	6.000
Raduis (R1) (mm)	5.614
Frequency (Hz)	659.253
Wave number	0.01226
Plate width (mm)	72.257
Half-plate width (mm)	36.128
Cross-sectional area (sq. mm)	1661.903
Open end correction (.6133r) (mm)	7.053
L1 (mm)	98.859
Effective length (mm)	256.314
COT(KL)	25.691
L 2 (mm)	103.268
Computed length (mm)	224.372

f1 pipe 42

Mouth ratio calculated as	2.58300
Ratio of mouth width:diameter	4.45903
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9220
Elliptic function K(e)	0.730
K(e)/0.89	0.820
Pipe Diameter (mm)	22.000
Radius (R2) (mm)	11.000
Mouth width (mm)	15.500
Mouth height (mm)	6.001
Raduis (R1) (mm)	5.441
Frequency (Hz)	698.454
Wave number	0.01299
Plate width (mm)	69.115
Half-plate width (mm)	34.558
Cross-sectional area (sq. mm)	1520.531
Open end correction (.6133r) (mm)	6.746
L1 (mm)	93.309
Effective length (mm)	241.928
COT(KL)	23.698
L 2 (mm)	97.975
Computed length (mm)	212.193

f#1 pipe 43

Mouth ratio calculated as	2.72700
Ratio of mouth width:diameter	4.29351
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9303
Elliptic function K(e)	0.744

K(e)/0.89	0.836
Pipe Diameter (mm)	20.500
Radius (R2) (mm)	10.250
Mouth width (mm)	15.000
Mouth height (mm)	5.501
Raduis (R1) (mm)	5.125
Frequency (Hz)	739.985
Wave number	0.01376
Plate width (mm)	64.403
Half-plate width (mm)	32.201
Cross-sectional area (sq. mm)	1320.254
Open end correction (.6133r) (mm)	6.286
L1 (mm)	88.630
Effective length (mm)	228.350
COT(KL)	22.284
L 2 (mm)	92.552
Computed length (mm)	200.441

g1 pipe 44

Mouth ratio calculated as	2.90000
Ratio of mouth width:diameter	4.33323
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9387
Elliptic function K(e)	0.763
K(e)/0.89	0.857
Pipe Diameter (mm)	20.000
Radius (R2) (mm)	10.000
Mouth width (mm)	14.500
Mouth height (mm)	5.000
Raduis (R1) (mm)	4.804
Frequency (Hz)	783.987
Wave number	0.01458
Plate width (mm)	62.832
Half-plate width (mm)	31.416
Cross-sectional area (sq. mm)	1256.637
Open end correction (.6133r) (mm)	6.133
L1 (mm)	81.991
Effective length (mm)	215.534
COT(KL)	23.192
L 2 (mm)	85.402
Computed length (mm)	187.036

g# pipe 45

Mouth ratio calculated as	2.91700
Ratio of mouth width:diameter	4.37579
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9394
Elliptic function K(e)	0.765
K(e)/0.89	0.859
Pipe Diameter (mm)	19.500
Radius (R2) (mm)	9.750
Mouth width (mm)	14.000
Mouth height (mm)	4.799
Raduis (R1) (mm)	4.625

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Frequency (Hz)	830.605
Wave number	0.01544
Plate width (mm)	61.261
Half-plate width (mm)	30.631
Cross-sectional area (sq. mm)	1194.591
Open end correction (.6133r) (mm)	5.980
L1 (mm)	76.375
Effective length (mm)	203.437
COT(KL)	22.958
L 2 (mm)	79.656
Computed length (mm)	175.395

al pipe 46

Mouth ratio calculated as	2.80000
Ratio of mouth width:diameter	4.26359
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9340
Elliptic function K(e)	0.752
K(e)/0.89	0.845
Pipe Diameter (mm)	19.000
Radius (R2) (mm)	9.500
Mouth width (mm)	14.000
Mouth height (mm)	5.000
Raduis (R1) (mm)	4.720
Frequency (Hz)	879.995
Wave number	0.01636
Plate width (mm)	59.690
Half-plate width (mm)	29.845
Cross-sectional area (sq. mm)	1134.115
Open end correction (.6133r) (mm)	5.826
L1 (mm)	72.403
Effective length (mm)	192.019
COT(KL)	20.998
L 2 (mm)	75.783
Computed length (mm)	165.967

a#1 pipe 47

Mouth ratio calculated as	2.70000
Ratio of mouth width:diameter	4.30515
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9289
Elliptic function K(e)	0.741
K(e)/0.89	0.833
Pipe Diameter (mm)	18.500
Radius (R2) (mm)	9.250
Mouth width (mm)	13.500
Mouth height (mm)	5.000
Raduis (R1) (mm)	4.635
Frequency (Hz)	932.321
Wave number	0.01733
Plate width (mm)	58.119
Half-plate width (mm)	29.060
Cross-sectional area (sq. mm)	1075.210
Open end correction (.6133r) (mm)	5.673

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L1 (mm)	67.880
Effective length (mm)	181.242
COT(KL)	19.989
L 2 (mm)	71.379
Computed length (mm)	156.327

b1 pipe 48

Mouth ratio calculated as	2.60000
Ratio of mouth width:diameter	4.34990
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9231
Elliptic function K(e)	0.731
K(e)/0.89	0.822
Pipe Diameter (mm)	18.000
Radius (R2) (mm)	9.000
Mouth width (mm)	13.000
Mouth height (mm)	5.000
Raduis (R1) (mm)	4.549
Frequency (Hz)	987.759
Wave number	0.01836
Plate width (mm)	56.549
Half-plate width (mm)	28.274
Cross-sectional area (sq. mm)	1017.876
Open end correction (.6133r) (mm)	5.520
L1 (mm)	63.646
Effective length (mm)	171.070
COT(KL)	19.020
L 2 (mm)	67.236
Computed length (mm)	147.251

c2 pipe 49

Mouth ratio calculated as	2.60000
Ratio of mouth width:diameter	4.10824
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9231
Elliptic function K(e)	0.731
K(e)/0.89	0.822
Pipe Diameter (mm)	17.000
Radius (R2) (mm)	8.500
Mouth width (mm)	13.000
Mouth height (mm)	5.000
Raduis (R1) (mm)	4.549
Frequency (Hz)	1046.494
Wave number	0.01946
Plate width (mm)	53.407
Half-plate width (mm)	26.704
Cross-sectional area (sq. mm)	907.920
Open end correction (.6133r) (mm)	5.213
L1 (mm)	61.100
Effective length (mm)	161.468
COT(KL)	16.965
L 2 (mm)	64.348
Computed length (mm)	139.869

c#2 pipe 50

Mouth ratio calculated as	2.60400
Ratio of mouth width:diameter	4.14690
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9233
Elliptic function K(e)	0.732
K(e)/0.89	0.822
Pipe Diameter (mm)	16.500
Radius (R2) (mm)	8.250
Mouth width (mm)	12.500
Mouth height (mm)	4.800
Raduis (R1) (mm)	4.370
Frequency (Hz)	1108.721
Wave number	0.02061
Plate width (mm)	51.836
Half-plate width (mm)	25.918
Cross-sectional area (sq. mm)	855.299
Open end correction (.6133r) (mm)	5.060
L1 (mm)	57.023
Effective length (mm)	152.406
COT(KL)	16.643
L 2 (mm)	60.170
Computed length (mm)	131.313

d2 pipe 51

Mouth ratio calculated as	2.60400
Ratio of mouth width:diameter	4.02124
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9233
Elliptic function K(e)	0.732
K(e)/0.89	0.822
Pipe Diameter (mm)	16.000
Radius (R2) (mm)	8.000
Mouth width (mm)	12.500
Mouth height (mm)	4.800
Raduis (R1) (mm)	4.370
Frequency (Hz)	1174.649
Wave number	0.02184
Plate width (mm)	50.265
Half-plate width (mm)	25.133
Cross-sectional area (sq. mm)	804.248
Open end correction (.6133r) (mm)	4.906
L1 (mm)	53.884
Effective length (mm)	143.852
COT(KL)	15.650
L 2 (mm)	56.846
Computed length (mm)	123.866

d#2 pipe 52

Mouth ratio calculated as	2.85600
Ratio of mouth width:diameter	4.09773
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147

Eccentricity of ellipse (e)	0.9367
Elliptic function K(e)	0.758
K(e)/0.89	0.852
Pipe Diameter (mm)	15.000
Radius (R2) (mm)	7.500
Mouth width (mm)	11.500
Mouth height (mm)	4.027
Raduis (R1) (mm)	3.839
Frequency (Hz)	1244.496
Wave number	0.02314
Plate width (mm)	47.124
Half-plate width (mm)	23.562
Cross-sectional area (sq. mm)	706.858
Open end correction (.6133r) (mm)	4.600
L1 (mm)	49.949
Effective length (mm)	135.778
COT(KL)	16.221
L 2 (mm)	52.372
Computed length (mm)	115.661

e2 pipe 53

Mouth ratio calculated as	2.75000
Ratio of mouth width:diameter	3.99839
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9315
Elliptic function K(e)	0.747
K(e)/0.89	0.839
Pipe Diameter (mm)	14.000
Radius (R2) (mm)	7.000
Mouth width (mm)	11.000
Mouth height (mm)	4.000
Raduis (R1) (mm)	3.742
Frequency (Hz)	1318.497
Wave number	0.02451
Plate width (mm)	43.982
Half-plate width (mm)	21.991
Cross-sectional area (sq. mm)	615.752
Open end correction (.6133r) (mm)	4.293
L1 (mm)	47.954
Effective length (mm)	128.158
COT(KL)	14.278
L 2 (mm)	50.344
Computed length (mm)	110.130

f2 pipe 54

Mouth ratio calculated as	2.62500
Ratio of mouth width:diameter	4.03919
Temperature in degrees K	284.14990
Speed of sound (m per sec)	337.95147
Eccentricity of ellipse (e)	0.9246
Elliptic function K(e)	0.734
K(e)/0.89	0.824
Pipe Diameter (mm)	13.500
Radius (R2) (mm)	6.750
Mouth width (mm)	10.500

Mouth height (mm)	4.000
Raduis (R1) (mm)	3.656
Frequency (Hz)	1396.898
Wave number	0.02597
Plate width (mm)	42.411
Half-plate width (mm)	21.206
Cross-sectional area (sq. mm)	572.555
Open end correction (.6133r) (mm)	4.140
L1 (mm)	45.149
Effective length (mm)	120.965
COT(KL)	13.355
L 2 (mm)	47.627
Computed length (mm)	103.970

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APPENDIX F

Broken constant scales

Pedal Principal 16

Diameter halving on step 17.5	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	250.00	125.00	196.35	49.09	55.39
C£/Db	240.29	120.15	188.72	47.18	53.24
D	230.96	115.48	181.40	45.35	51.17
D£/Eb	221.99	111.00	174.35	43.59	49.18
E	213.37	106.68	167.58	41.90	47.27
F	205.08	102.54	161.07	40.27	45.44
F£/Gb	197.12	98.56	154.82	38.70	43.67
G	189.46	94.73	148.81	37.20	41.98
G£/Ab	182.11	91.05	143.03	35.76	40.35
A	175.03	87.52	137.47	34.37	38.78
A£/Bb	168.24	84.12	132.13	33.03	37.27
B	161.70	80.85	127.00	31.75	35.83

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	32.70	0.00061	785.398	392.699	196349.50
C£/Db	34.64	0.00064	754.898	377.449	181395.44
D	36.70	0.00068	725.582	362.791	167580.19
D£/Eb	38.89	0.00072	697.405	348.702	154817.31
E	41.20	0.00076	670.322	335.161	143026.50
F	43.65	0.00081	644.290	322.145	132133.50
F£/Gb	46.24	0.00086	619.269	309.635	122070.13
G	48.99	0.00091	595.221	297.610	112773.25
G£/Ab	51.91	0.00096	572.106	286.053	104184.38
A	54.99	0.00102	549.888	274.944	96249.63
A£/Bb	58.26	0.00108	528.534	264.267	88919.19
B	61.73	0.00115	508.009	254.004	82147.13

	OPEN END COR	COTKL	L1	L2
C	76.66	367.40	2511.61	2226.78
C£/Db	73.69	353.13	2369.31	2095.75
D	70.82	339.42	2235.06	1972.33
D£/Eb	68.07	326.24	2108.39	1856.06
E	65.43	313.57	1988.88	1746.55
F	62.89	301.39	1876.12	1643.40
F£/Gb	60.45	289.69	1769.73	1546.25
G	58.10	278.44	1669.36	1454.75
G£/Ab	55.84	267.63	1574.66	1368.58
A	53.67	257.23	1485.31	1287.43
A£/Bb	51.59	247.24	1401.02	1211.02
B	49.59	237.64	1321.50	1139.06

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	4738.39	5176.54	4.00	4.00	6.122757
C£/Db	4465.07	4886.00	4.00	4.00	5.717674
D	4207.39	4611.77	4.00	4.00	5.339416
D£/Eb	3964.45	4352.93	4.00	4.00	4.986209
E	3735.42	4108.62	4.00	4.00	4.656392
F	3519.52	3878.01	4.00	4.00	4.348416
F£/Gb	3315.98	3660.36	4.00	4.00	4.060838
G	3124.11	3454.92	4.00	4.00	3.792308
G£/Ab	2943.24	3261.00	4.00	4.00	3.541565
A	2772.75	3077.98	4.00	4.00	3.307431
A£/Bb	2612.04	2905.22	4.00	4.00	3.088808
B	2460.56	2742.16	4.00	4.00	2.884671

Diameter halving on step 14.6	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	155.50	77.75	122.13	30.53	34.45
C£/Db	148.29	74.15	116.47	29.12	32.86
D	141.42	70.71	111.07	27.77	31.33
D£/Eb	134.87	67.44	105.93	26.48	29.88
E	128.62	64.31	101.02	25.25	28.50
F	122.66	61.33	96.34	24.08	27.18
F£/Gb	116.98	58.49	91.87	22.97	25.92
G	111.56	55.78	87.62	21.90	24.72
G£/Ab	106.39	53.19	83.56	20.89	23.57
A	101.46	50.73	79.69	19.92	22.48
A£/Bb	96.76	48.38	75.99	19.00	21.44
B	92.27	46.14	72.47	18.12	20.44

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	65.40	0.00121	488.518	244.259	75964.50
C£/Db	69.29	0.00129	465.882	232.941	69087.88
D	73.41	0.00136	444.295	222.148	62833.80
D£/Eb	77.77	0.00144	423.708	211.854	57145.82
E	82.40	0.00153	404.075	202.038	51972.72
F	87.30	0.00162	385.353	192.676	47267.99
F£/Gb	92.49	0.00172	367.497	183.749	42989.05
G	97.99	0.00182	350.469	175.234	39097.53
G£/Ab	103.82	0.00193	334.230	167.115	35558.25
A	109.99	0.00204	318.743	159.371	32339.38
A£/Bb	116.53	0.00216	303.974	151.987	29411.90
B	123.46	0.00229	289.889	144.945	26749.41

	OPEN END COR	COTKL	L1	L2
C	47.68	228.52	1246.45	1071.21
C£/Db	45.47	217.94	1176.03	1009.02

D	43.37	207.84	1109.57	950.41
D£/Eb	41.36	198.21	1046.87	895.18
E	39.44	189.02	987.71	843.15
F	37.61	180.26	931.89	794.12
F£/Gb	35.87	171.91	879.22	747.92
G	34.21	163.95	829.52	704.40
G£/Ab	32.62	156.35	782.63	663.39
A	31.11	149.11	738.38	624.75
A£/Bb	29.67	142.20	696.63	588.35
B	28.30	135.61	657.25	554.06

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	2317.67	2588.27	4.00	4.00	2.695376
C£/Db	2185.04	2443.00	4.00	4.00	2.497633
D	2059.98	2305.88	4.00	4.00	2.314429
D£/Eb	1942.06	2176.46	4.00	4.00	2.144694
E	1830.86	2054.31	4.00	4.00	1.987440
F	1726.01	1939.01	4.00	4.00	1.841750
F£/Gb	1627.14	1830.18	4.00	4.00	1.706773
G	1533.92	1727.46	4.00	4.00	1.581723
G£/Ab	1446.02	1630.50	4.00	4.00	1.465871
A	1363.14	1538.99	4.00	4.00	1.358541
A£/Bb	1284.99	1452.61	4.00	4.00	1.259106
B	1211.31	1371.08	4.00	4.00	1.166986

Diameter halving on step 20.0	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	88.00	44.00	69.12	17.28	19.50
C£/Db	85.00	42.50	66.76	16.69	18.83
D	82.11	41.05	64.49	16.12	18.19
D£/Eb	79.31	39.66	62.29	15.57	17.57
E	76.61	38.30	60.17	15.04	16.97
F	74.00	37.00	58.12	14.53	16.39

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	130.81	0.00243	276.460	138.230	24328.49
C£/Db	138.59	0.00257	267.043	133.521	22699.29
D	146.83	0.00273	257.946	128.973	21179.18
D£/Eb	155.56	0.00289	249.160	124.580	19760.88
E	164.81	0.00306	240.672	120.336	18437.54
F	174.61	0.00324	232.474	116.237	17202.84

	OPEN END COR	COTKL	L1	L2
C	26.99	129.33	620.03	521.71
C£/Db	26.07	124.92	584.64	489.83
D	25.18	120.67	551.25	459.85
D£/Eb	24.32	116.55	519.75	431.64

E	23.49	112.58	490.05	405.11
F	22.69	108.75	462.02	380.16

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	1141.74	1294.04	4.00	4.00	1.081620
C£/Db	1074.47	1221.41	4.00	4.00	1.015530
D	1011.10	1152.85	4.00	4.00	0.953534
D£/Eb	951.40	1088.15	4.00	4.00	0.895381
E	895.16	1027.08	4.00	4.00	0.840836
F	842.18	969.43	4.00	4.00	0.789679

Pedal Octave 8

Diameter halving on step 20.8	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	147.00	73.50	115.45	28.86	32.57
C£/Db	142.18	71.09	111.66	27.92	31.50
D	137.51	68.75	108.00	27.00	30.47
D£/Eb	133.00	66.50	104.45	26.11	29.47
E	128.63	64.32	101.03	25.26	28.50
F	124.41	62.20	97.71	24.43	27.56
F£/Gb	120.33	60.16	94.50	23.63	26.66
G	116.38	58.19	91.40	22.85	25.78
G£/Ab	112.56	56.28	88.40	22.10	24.94
A	108.86	54.43	85.50	21.37	24.12
A£/Bb	105.29	52.64	82.69	20.67	23.33
B	101.83	50.92	79.98	19.99	22.56

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	65.40	0.00121	461.814	230.907	67886.63
C£/Db	69.29	0.00129	446.656	223.328	63503.50
D	73.41	0.00136	431.996	215.998	59403.27
D£/Eb	77.77	0.00144	417.817	208.909	55567.84
E	82.40	0.00153	404.104	202.052	51980.04
F	87.30	0.00162	390.841	195.420	48623.87
F£/Gb	92.49	0.00172	378.012	189.006	45484.39
G	97.99	0.00182	365.605	182.803	42547.68
G£/Ab	103.82	0.00193	353.606	176.803	39800.53
A	109.99	0.00204	342.000	171.000	37230.72
A£/Bb	116.53	0.00216	330.775	165.387	34826.89
B	123.46	0.00229	319.918	159.959	32578.25

	OPEN END COR	COTKL	L1	L2
C	45.08	216.03	1249.06	1082.86
C£/Db	43.60	208.94	1177.90	1017.38
D	42.17	202.08	1110.77	955.74
D£/Eb	40.78	195.45	1047.45	897.73

E	39.44	189.04	987.71	843.13
F	38.15	182.83	931.35	791.75
F£/Gb	36.90	176.83	878.19	743.41
G	35.69	171.03	828.04	697.92
G£/Ab	34.52	165.41	780.74	655.12
A	33.38	159.98	736.11	614.86
A£/Bb	32.29	154.73	694.02	576.99
B	31.23	149.65	654.31	541.37

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	2331.92	2588.27	4.00	4.00	2.547846
C£/Db	2195.28	2443.00	4.00	4.00	2.394412
D	2066.52	2305.88	4.00	4.00	2.250256
D£/Eb	1945.18	2176.46	4.00	4.00	2.114820
E	1830.84	2054.31	4.00	4.00	1.987580
F	1723.11	1939.01	4.00	4.00	1.868040
F£/Gb	1621.60	1830.18	4.00	4.00	1.755738
G	1525.96	1727.46	4.00	4.00	1.650239
G£/Ab	1435.86	1630.50	4.00	4.00	1.551131
A	1350.97	1538.99	4.00	4.00	1.458032
A£/Bb	1271.01	1452.61	4.00	4.00	1.370581
B	1195.68	1371.08	4.00	4.00	1.288437

Diameter halving on step 14.2

Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	98.50	49.25	77.36	19.34	21.82
C£/Db	93.80	46.90	73.67	18.42	20.78
D	89.33	44.67	70.16	17.54	19.79
D£/Eb	85.07	42.54	66.82	16.70	18.85
E	81.02	40.51	63.63	15.91	17.95
F	77.16	38.58	60.60	15.15	17.09
F£/Gb	73.48	36.74	57.71	14.43	16.28
G	69.97	34.99	54.96	13.74	15.50
G£/Ab	66.64	33.32	52.34	13.08	14.76
A	63.46	31.73	49.84	12.46	14.06
A£/Bb	60.44	30.22	47.47	11.87	13.39
B	57.55	28.78	45.20	11.30	12.75

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	130.81	0.00243	309.447	154.723	30480.52
C£/Db	138.59	0.00257	294.694	147.347	27643.55
D	146.83	0.00273	280.645	140.323	25070.63
D£/Eb	155.56	0.00289	267.266	133.633	22737.20
E	164.81	0.00306	254.524	127.262	20620.95
F	174.61	0.00324	242.390	121.195	18701.66
F£/Gb	184.99	0.00343	230.835	115.417	16961.01

G	195.99	0.00364	219.830	109.915	15382.36
G£/Ab	207.65	0.00385	209.350	104.675	13950.66
A	220.00	0.00408	199.369	99.685	12652.21
A£/Bb	233.08	0.00433	189.864	94.932	11474.60
B	246.94	0.00458	180.813	90.406	10406.61

	OPEN END COR	COTKL	L1	L2
C	30.21	144.76	616.81	507.81
C£/Db	28.77	137.86	581.94	478.23
D	27.39	131.28	549.03	450.35
D£/Eb	26.09	125.02	517.99	424.09
E	24.84	119.06	488.69	399.35
F	23.66	113.39	461.06	376.05
F£/Gb	22.53	107.98	434.98	354.10
G	21.46	102.83	410.37	333.43
G£/Ab	20.43	97.93	387.16	313.95
A	19.46	93.26	365.26	295.61
A£/Bb	18.53	88.82	344.59	278.33
B	17.65	84.58	325.10	262.05

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	1124.63	1294.04	4.00	4.00	1.211354
C£/Db	1060.16	1221.41	4.00	4.00	1.121294
D	999.38	1152.85	4.00	4.00	1.037979
D£/Eb	942.08	1088.15	4.00	4.00	0.960906
E	888.05	1027.08	4.00	4.00	0.889608
F	837.11	969.43	4.00	4.00	0.823652
F£/Gb	789.08	915.02	4.00	4.00	0.762639
G	743.80	863.66	4.00	4.00	0.706201
G£/Ab	701.11	815.19	4.00	4.00	0.653995
A	660.86	769.44	4.00	4.00	0.605706
A£/Bb	622.92	726.25	4.00	4.00	0.561039
B	587.15	685.49	4.00	4.00	0.519726

Diameter halving on step 15.0	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	54.80	27.40	43.04	10.76	12.14
C£/Db	52.33	26.16	41.10	10.27	11.59
D	49.97	24.98	39.24	9.81	11.07
D£/Eb	47.71	23.86	37.47	9.37	10.57
E	45.56	22.78	35.78	8.95	10.09
F	43.50	21.75	34.17	8.54	9.64

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	261.62	0.00486	172.159	86.080	9434.33
C£/Db	277.18	0.00514	164.390	82.195	8602.01

D	293.66	0.00545	156.971	78.486	7643.14
D£/Eb	311.12	0.00577	149.887	74.944	7151.21
E	329.62	0.00612	143.123	71.561	6520.31
F	349.22	0.00648	136.664	68.332	5945.08

	OPEN END COR	COTKL	L1	L2
C	16.80	80.53	306.70	246.74
C£/Db	16.05	76.90	289.31	232.12
D	15.32	73.43	272.89	218.37
D£/Eb	14.63	70.12	257.41	205.41
E	13.97	66.95	242.80	193.22
F	13.34	63.93	229.02	181.75

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	553.44	647.02	4.00	4.00	0.481420
C£/Db	521.43	610.70	4.00	4.00	0.447300
D	491.26	576.43	4.00	4.00	0.415665
D£/Eb	462.82	544.07	4.00	4.00	0.386336
E	436.02	513.54	4.00	4.00	0.359146
F	410.77	484.71	4.00	4.00	0.333942

Great Principal 8

Diameter halving on step 17.6	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	138.00	69.00	108.38	27.10	30.57
C£/Db	132.67	66.33	104.20	26.05	29.39
D	127.54	63.77	100.17	25.04	28.26
D£/Eb	122.61	61.31	96.30	24.08	27.17
E	117.88	58.94	92.58	23.14	26.12
F	113.32	56.66	89.00	22.25	25.11
F£/Gb	108.94	54.47	85.56	21.39	24.14
G	104.73	52.37	82.26	20.56	23.20
G£/Ab	100.69	50.34	79.08	19.77	22.31
A	96.80	48.40	76.02	19.01	21.45
A£/Bb	93.06	46.53	73.09	18.27	20.62
B	89.46	44.73	70.26	17.57	19.82

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	65.40	0.00121	433.540	216.770	59828.50
C£/Db	69.29	0.00129	416.788	208.394	55294.32
D	73.41	0.00136	400.683	200.342	51103.77
D£/Eb	77.77	0.00144	385.201	192.601	47230.89
E	82.40	0.00153	370.317	185.159	43651.42
F	87.30	0.00162	356.009	178.004	40343.26
F£/Gb	92.49	0.00172	342.252	171.126	37285.82
G	97.99	0.00182	329.028	164.514	34460.07
G£/Ab	103.82	0.00193	316.314	158.157	31848.47

A	109.99	0.00204	304.092	152.046	29434.83
A£/Bb	116.53	0.00216	292.343	146.171	27204.09
B	123.46	0.00229	281.046	140.523	25142.38

	OPEN END COR	COTKL	L1	L2
C	42.32	202.81	1251.82	1095.28
C£/Db	40.68	194.97	1180.82	1030.47
D	39.11	187.44	1113.83	969.43
D£/Eb	37.60	180.19	1050.63	911.94
E	36.15	173.23	991.01	857.81
F	34.75	166.54	934.75	806.84
F£/Gb	33.41	160.10	881.68	758.84
G	32.12	153.92	831.61	713.65
G£/Ab	30.88	147.97	784.38	671.11
A	29.68	142.25	739.81	631.05
A£/Bb	28.54	136.76	697.77	593.34
B	27.43	131.47	658.11	557.84

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	2347.10	2588.27	4.00	4.00	2.391664
C£/Db	2211.29	2443.00	4.00	4.00	2.234075
D	2083.26	2305.88	4.00	4.00	2.086899
D£/Eb	1962.58	2176.46	4.00	4.00	1.949450
E	1848.82	2054.31	4.00	4.00	1.821085
F	1741.59	1939.01	4.00	4.00	1.701206
F£/Gb	1640.53	1830.18	4.00	4.00	1.589252
G	1545.27	1727.46	4.00	4.00	1.484703
G£/Ab	1455.48	1630.50	4.00	4.00	1.387068
A	1370.86	1538.99	4.00	4.00	1.295893
A£/Bb	1291.11	1452.61	4.00	4.00	1.210752
B	1215.95	1371.08	4.00	4.00	1.131245

Diameter halving on step 21.6	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	86.00	43.00	67.54	16.89	19.05
C£/Db	83.28	41.64	65.41	16.35	18.45
D	80.65	40.33	63.34	15.84	17.87
D£/Eb	78.10	39.05	61.34	15.34	17.30
E	75.64	37.82	59.40	14.85	16.76
F	73.25	36.62	57.53	14.38	16.23
F£/Gb	70.93	35.47	55.71	13.93	15.72
G	68.69	34.35	53.95	13.49	15.22
G£/Ab	66.52	33.26	52.24	13.06	14.74
A	64.42	32.21	50.59	12.65	14.27
A£/Bb	62.38	31.19	49.00	12.25	13.82
B	60.41	30.21	47.45	11.86	13.38

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	130.81	0.00243	270.177	135.088	23235.22
C£/Db	138.59	0.00257	261.641	130.820	21790.17
D	146.83	0.00273	253.374	126.687	20434.99
D£/Eb	155.56	0.00289	245.369	122.684	19164.11
E	164.81	0.00306	237.616	118.808	17972.25
F	174.61	0.00324	230.109	115.054	16854.51
F£/Gb	184.99	0.00343	222.839	111.419	15806.32
G	195.99	0.00364	215.798	107.899	14823.27
G£/Ab	207.65	0.00385	208.980	104.490	13901.40
A	220.00	0.00408	202.377	101.189	13036.84
A£/Bb	233.08	0.00433	195.983	97.991	12226.05
B	246.94	0.00458	189.791	94.895	11465.70

	OPEN END COR	COTKL	L1	L2
C	26.37	126.39	620.65	524.39
C£/Db	25.54	122.39	585.16	492.13
D	24.73	118.53	551.70	461.78
D£/Eb	23.95	114.78	520.12	433.24
E	23.19	111.15	490.34	406.39
F	22.46	107.64	462.25	381.14
F£/Gb	21.75	104.24	435.76	357.41
G	21.06	100.95	410.77	335.09
G£/Ab	20.40	97.76	387.20	314.10
A	19.75	94.67	364.96	294.38
A£/Bb	19.13	91.68	344.00	275.84
B	18.53	88.78	324.22	258.43

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	1145.03	1294.04	4.00	4.00	1.056928
C£/Db	1077.29	1221.41	4.00	4.00	0.994882
D	1013.48	1152.85	4.00	4.00	0.936535
D£/Eb	953.36	1088.15	4.00	4.00	0.881670
E	896.74	1027.08	4.00	4.00	0.830082
F	843.40	969.43	4.00	4.00	0.781578
F£/Gb	793.16	915.02	4.00	4.00	0.735980
G	745.85	863.66	4.00	4.00	0.693115
G£/Ab	701.30	815.19	4.00	4.00	0.652826
A	659.34	769.44	4.00	4.00	0.614962
A£/Bb	619.84	726.25	4.00	4.00	0.579382
B	582.64	685.49	4.00	4.00	0.545954

Diameter halving on step 14.1	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	58.50	29.25	45.95	11.49	12.96
C£/Db	55.70	27.85	43.75	10.94	12.34

D	53.04	26.52	41.66	10.41	11.75
D£/Eb	50.50	25.25	39.67	9.92	11.19
E	48.09	24.05	37.77	9.44	10.65
F	45.79	22.90	35.96	8.99	10.15
F£/Gb	43.60	21.80	34.25	8.56	9.66
G	41.52	20.76	32.61	8.15	9.20
G£/Ab	39.53	19.77	31.05	7.76	8.76
A	37.64	18.82	29.57	7.39	8.34
A£/Bb	35.84	17.92	28.15	7.04	7.94
B	34.13	17.07	26.81	6.70	7.56

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	261.62	0.00486	183.783	91.892	10751.32
C£/Db	277.18	0.00514	174.997	87.499	9747.95
D	293.66	0.00545	166.632	83.316	8838.22
D£/Eb	311.12	0.00577	158.666	79.333	8013.39
E	329.62	0.00612	151.081	75.540	7265.54
F	349.22	0.00648	143.858	71.929	6587.48
F£/Gb	369.99	0.00687	136.981	68.491	5972.71
G	391.99	0.00728	130.433	65.216	5415.30
G£/Ab	415.30	0.00771	124.197	62.099	4909.92
A	439.99	0.00817	118.260	59.130	4451.70
A£/Bb	466.16	0.00865	112.607	56.303	4036.25
B	493.87	0.00917	107.223	53.612	3659.56

	OPEN END COR	COTKL	L1	L2
C	17.94	85.97	305.57	242.07
C£/Db	17.08	81.86	288.27	227.87
D	16.26	77.95	271.95	214.50
D£/Eb	15.49	74.22	256.55	201.92
E	14.75	70.67	242.02	190.06
F	14.04	67.30	228.32	178.90
F£/Gb	13.37	64.08	215.38	168.39
G	12.73	61.02	203.18	158.49
G£/Ab	12.12	58.10	191.67	149.17
A	11.54	55.32	180.82	140.40
A£/Bb	10.99	52.68	170.57	132.14
B	10.47	50.16	160.91	124.36

C

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	547.64	647.02	4.00	4.00	0.514522
C£/Db	516.14	610.70	4.00	4.00	0.476747
D	486.45	576.43	4.00	4.00	0.441817
D£/Eb	458.47	544.07	4.00	4.00	0.409518
E	432.08	513.54	4.00	4.00	0.379655
F	407.22	484.71	4.00	4.00	0.352045
F£/Gb	383.77	457.51	4.00	4.00	0.326519
G	361.68	431.83	4.00	4.00	0.302922
G£/Ab	340.85	407.59	4.00	4.00	0.281109
A	321.21	384.72	4.00	4.00	0.260948
A£/Bb	302.71	363.13	4.00	4.00	0.242314
B	285.26	342.74	4.00	4.00	0.225094

Diameter halving on step 19.7	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	32.50	16.25	25.53	6.38	7.20
C£/Db	31.38	15.69	24.64	6.16	6.95
D	30.29	15.15	23.79	5.95	6.71
D£/Eb	29.24	14.62	22.97	5.74	6.48
E	28.23	14.12	22.17	5.54	6.25
F	27.25	13.63	21.41	5.35	6.04
F£/Gb	26.31	13.16	20.67	5.17	5.83
G	25.40	12.70	19.95	4.99	5.63
G£/Ab	24.52	12.26	19.26	4.82	5.43
A	23.67	11.84	18.59	4.65	5.25
A£/Bb	22.86	11.43	17.95	4.49	5.06
B	22.07	11.03	17.33	4.33	4.89

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	523.25	0.00971	102.102	51.051	3318.31
C£/Db	554.36	0.01029	98.570	49.285	3092.72
D	587.33	0.01090	95.160	47.580	2882.46
D£/Eb	622.25	0.01155	91.869	45.934	2686.49
E	659.25	0.01224	88.691	44.345	2503.85
F	698.46	0.01296	85.623	42.812	2333.63
F£/Gb	739.99	0.01373	82.661	41.331	2174.98
G	783.99	0.01455	79.802	39.901	2027.11
G£/Ab	830.61	0.01542	77.042	38.521	1889.30
A	880.00	0.01633	74.377	37.188	1760.86
A£/Bb	932.33	0.01730	71.804	35.902	1641.15
B	987.77	0.01833	69.320	34.660	1529.57

	OPEN END COR	COTKL	L1	L2
C	9.97	47.76	151.79	117.03
C£/Db	9.62	46.11	143.05	109.62
D	9.29	44.52	134.82	102.66
D£/Eb	8.97	42.98	127.05	96.12
E	8.66	41.49	119.72	89.99
F	8.36	40.05	112.82	84.23
F£/Gb	8.07	38.67	106.31	78.83
G	7.79	37.33	100.17	73.76
G£/Ab	7.52	36.04	94.38	69.00
A	7.26	34.79	88.92	64.54
A£/Bb	7.01	33.59	83.77	60.35
B	6.77	32.43	78.92	56.43

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	268.82	323.50	4.00	4.00	0.209190
C£/Db	252.67	305.35	4.00	4.00	0.197362

D	237.47	288.21	4.00	4.00	0.186328
D£/Eb	223.17	272.03	4.00	4.00	0.176042
E	209.72	256.76	4.00	4.00	0.166460
F	197.05	242.35	4.00	4.00	0.157542
F£/Gb	185.14	228.75	4.00	4.00	0.149251
G	173.92	215.91	4.00	4.00	0.141552
G£/Ab	163.38	203.79	4.00	4.00	0.134413
A	153.46	192.36	4.00	4.00	0.127802
A£/Bb	144.12	181.56	4.00	4.00	0.121692
B	135.35	171.37	4.00	4.00	0.116057

Diameter halving on step 14.4	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	21.30	10.65	16.73	4.18	4.72
C£/Db	20.30	10.15	15.94	3.99	4.50
D	19.34	9.67	15.19	3.80	4.29
D£/Eb	18.43	9.22	14.48	3.62	4.08
E	17.56	8.78	13.80	3.45	3.89
F	16.74	8.37	13.15	3.29	3.71
F£/Gb	15.95	7.98	12.53	3.13	3.53
G	15.20	7.60	11.94	2.98	3.37

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	1046.49	0.01942	66.916	33.458	1425.31
C£/Db	1108.72	0.02058	63.767	31.883	1294.32
D	1174.65	0.02180	60.766	30.383	1175.37
D£/Eb	1244.49	0.02310	57.907	28.953	1067.35
E	1318.50	0.02447	55.182	27.591	969.25
F	1396.90	0.02593	52.585	26.292	880.18
F£/Gb	1479.96	0.02747	50.110	25.055	799.29
G	1567.97	0.02910	47.752	23.876	725.83

	OPEN END COR	COTKL	L1	L2
C	6.53	31.30	74.34	52.75
C£/Db	6.22	29.83	70.11	49.58
D	5.93	28.43	66.12	46.60
D£/Eb	5.65	27.09	62.36	43.80
E	5.39	25.81	58.81	41.17
F	5.13	24.60	55.46	38.69
F£/Gb	4.89	23.44	52.30	36.36
G	4.66	22.34	49.32	34.17

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	127.10	161.75	4.00	4.00	0.110859
C£/Db	119.70	152.67	4.00	4.00	0.104423
D	112.73	144.11	4.00	4.00	0.098504
D£/Eb	106.16	136.02	4.00	4.00	0.093063
E	99.97	128.38	4.00	4.00	0.088067

F	94.15	121.18	4.00	4.00	0.083483
F£/Gb	88.66	114.38	4.00	4.00	0.079282
G	83.49	107.96	4.00	4.00	0.075436

Great Octave 4

Diameter halving on step 20.2	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	78.50	39.25	61.65	15.41	17.39
C£/Db	75.85	37.93	59.57	14.89	16.81
D	73.29	36.65	57.56	14.39	16.24
D£/Eb	70.82	35.41	55.62	13.91	15.69
E	68.43	34.22	53.75	13.44	15.16
F	66.12	33.06	51.93	12.98	14.65
F£/Gb	63.89	31.95	50.18	12.55	14.16
G	61.74	30.87	48.49	12.12	13.68
G£/Ab	59.66	29.83	46.85	11.71	13.22
A	57.64	28.82	45.27	11.32	12.77
A£/Bb	55.70	27.85	43.75	10.94	12.34
B	53.82	26.91	42.27	10.57	11.92

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	130.81	0.00243	246.615	123.308	19359.28
C£/Db	138.59	0.00257	238.296	119.148	18075.23
D	146.83	0.00273	230.258	115.129	16876.38
D£/Eb	155.56	0.00289	222.491	111.245	15757.02
E	164.81	0.00306	214.986	107.493	14711.93
F	174.61	0.00324	207.734	103.867	13736.14
F£/Gb	184.99	0.00343	200.727	100.363	12825.07
G	195.99	0.00364	193.956	96.978	11974.43
G£/Ab	207.65	0.00385	187.413	93.707	11180.21
A	220.00	0.00408	181.091	90.546	10438.66
A£/Bb	233.08	0.00433	174.983	87.491	9746.29
B	246.94	0.00458	169.080	84.540	9099.86

C

	OPEN END COR	COTKL	L1	L2
C	24.07	115.36	622.95	534.54
C£/Db	23.26	111.47	587.44	502.14
D	22.48	107.71	553.95	471.66
D£/Eb	21.72	104.08	522.36	442.97
E	20.98	100.57	492.55	415.97
F	20.28	97.18	464.44	390.57
F£/Gb	19.59	93.90	437.92	366.68
G	18.93	90.73	412.90	344.20
G£/Ab	18.29	87.67	389.30	323.05

A	17.68	84.71	367.04	303.16
A£/Bb	17.08	81.86	346.05	284.45
B	16.50	79.09	326.24	266.86

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	1157.48	1294.04	4.00	4.00	0.954380
C£/Db	1089.59	1221.41	4.00	4.00	0.905711
D	1025.61	1152.85	4.00	4.00	0.850656
D£/Eb	965.33	1088.15	4.00	4.00	0.798993
E	908.53	1027.08	4.00	4.00	0.750516
F	855.01	969.43	4.00	4.00	0.705032
F£/Gb	804.59	915.02	4.00	4.00	0.662358
G	757.09	863.66	4.00	4.00	0.622323
G£/Ab	712.35	815.19	4.00	4.00	0.584767
A	670.20	769.44	4.00	4.00	0.549540
A£/Bb	630.50	726.25	4.00	4.00	0.516501
B	593.11	685.49	4.00	4.00	0.485517

Diameter halving on step 14.6	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	52.00	26.00	40.84	10.21	11.52
C£/Db	49.59	24.79	38.95	9.74	10.99
D	47.29	23.64	37.14	9.28	10.48
D£/Eb	45.09	22.55	35.42	8.85	9.99
E	43.00	21.50	33.77	8.44	9.53
F	41.01	20.50	32.21	8.05	9.08
F£/Gb	39.10	19.55	30.71	7.68	8.66
G	37.29	18.64	29.29	7.32	8.26
G£/Ab	35.56	17.78	27.93	6.98	7.88
A	33.91	16.95	26.63	6.66	7.51
A£/Bb	32.34	16.17	25.40	6.35	7.16
B	30.84	15.42	24.22	6.05	6.83

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	261.62	0.00486	163.363	81.681	8494.87
C£/Db	277.18	0.00514	155.783	77.892	7724.88
D	293.66	0.00545	148.555	74.278	7024.67
D£/Eb	311.12	0.00577	141.663	70.831	6387.94
E	329.62	0.00612	135.090	67.545	5808.93
F	349.22	0.00648	128.822	64.411	5282.38
F£/Gb	369.99	0.00687	122.845	61.422	4803.58
G	391.99	0.00728	117.145	58.573	4368.17
G£/Ab	415.30	0.00771	111.710	55.855	3972.23
A	439.99	0.00817	106.527	53.263	3612.18
A£/Bb	466.16	0.00865	101.584	50.792	3284.76
B	493.87	0.00917	96.871	48.436	2987.03

	OPEN END COR	COTKL	L1	L2
C	15.95	76.42	307.56	250.33
C£/Db	15.21	72.87	290.15	235.63
D	14.50	69.49	273.71	221.78
D£/Eb	13.83	66.27	258.21	208.75
E	13.19	63.19	243.58	196.47
F	12.57	60.26	229.78	184.91
F£/Gb	11.99	57.47	216.76	174.02
G	11.43	54.80	204.48	163.77
G£/Ab	10.90	52.26	192.89	154.12
A	10.40	49.83	181.96	145.03
A£/Bb	9.92	47.52	171.65	136.48
B	9.46	45.32	161.92	128.42

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	557.90	647.02	4.00	4.00	0.456426
C£/Db	525.78	610.70	4.00	4.00	0.423466
D	495.50	576.43	4.00	4.00	0.392944
D£/Eb	466.96	544.07	4.00	4.00	0.364680
E	440.05	513.54	4.00	4.00	0.338509
F	414.69	484.71	4.00	4.00	0.314277
F£/Gb	390.78	457.51	4.00	4.00	0.291843
G	368.25	431.83	4.00	4.00	0.271074
G£/Ab	347.01	407.59	4.00	4.00	0.251848
A	326.99	384.72	4.00	4.00	0.234052
A£/Bb	308.12	363.13	4.00	4.00	0.217581
B	290.34	342.74	4.00	4.00	0.202338

Diameter halving on step 19.5	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	29.40	14.70	23.09	5.77	6.51
C£/Db	28.37	14.19	22.29	5.57	6.29
D	27.38	13.69	21.51	5.38	6.07
D£/Eb	26.43	13.21	20.76	5.19	5.86
E	25.51	12.75	20.03	5.01	5.65
F	24.62	12.31	19.33	4.83	5.45
F£/Gb	23.76	11.88	18.66	4.66	5.26
G	22.93	11.46	18.01	4.50	5.08
G£/Ab	22.13	11.06	17.38	4.35	4.90
A	21.36	10.68	16.77	4.19	4.73
A£/Bb	20.61	10.31	16.19	4.05	4.57
B	19.89	9.95	15.62	3.91	4.41

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	523.25	0.00971	92.363	46.181	2715.47
C£/Db	554.36	0.01029	89.141	44.570	2529.31

D	587.33	0.01090	86.031	43.015	2355.91
D£/Eb	622.25	0.01155	83.030	41.515	2194.40
E	659.25	0.01224	80.133	40.066	2043.96
F	698.46	0.01296	77.337	38.669	1903.83
F£/Gb	739.99	0.01373	74.639	37.320	1773.31
G	783.99	0.01455	72.035	36.018	1651.74
G£/Ab	830.61	0.01542	69.522	34.761	1538.50
A	880.00	0.01633	67.097	33.548	1433.03
A£/Bb	932.33	0.01730	64.756	32.378	1334.79
B	987.77	0.01833	62.497	31.249	1243.28

	OPEN END COR	COTKL	L1	L2
C	9.02	43.21	152.74	120.84
C£/Db	8.70	41.70	143.97	113.28
D	8.40	40.24	135.71	106.18
D£/Eb	8.10	38.84	127.91	99.51
E	7.82	37.49	120.56	93.24
F	7.55	36.18	113.63	87.35
F£/Gb	7.29	34.92	107.09	81.82
G	7.03	33.70	100.92	76.63
G£/Ab	6.79	32.52	95.11	71.75
A	6.55	31.39	89.63	67.17
A£/Bb	6.32	30.29	84.46	62.88
B	6.10	29.24	79.58	58.85

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	273.58	323.50	4.00	4.00	0.188203
C£/Db	257.25	305.35	4.00	4.00	0.177391
D	241.89	288.21	4.00	4.00	0.167299
D£/Eb	227.42	272.03	4.00	4.00	0.157885
E	213.80	256.76	4.00	4.00	0.149110
F	200.98	242.35	4.00	4.00	0.140936
F£/Gb	188.91	228.75	4.00	4.00	0.133329
G	177.55	215.91	4.00	4.00	0.126256
G£/Ab	166.86	203.79	4.00	4.00	0.119688
A	156.80	192.36	4.00	4.00	0.113595
A£/Bb	147.34	181.56	4.00	4.00	0.107952
B	138.43	171.37	4.00	4.00	0.102735

Diameter halving on step 13.8	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	19.20	9.60	15.08	3.77	4.25
C£/Db	18.26	9.13	14.34	3.59	4.05
D	17.36	8.68	13.64	3.41	3.85
D£/Eb	16.51	8.26	12.97	3.24	3.66
E	15.70	7.85	12.33	3.08	3.48

F	14.93	7.47	11.73	2.93	3.31
F£/Gb	14.20	7.10	11.15	2.79	3.15

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	1046.49	0.01942	60.319	30.159	1158.12
C£/Db	1108.72	0.02058	57.362	28.681	1047.35
D	1174.65	0.02180	54.550	27.275	947.18
D£/Eb	1244.49	0.02310	51.876	25.938	856.59
E	1318.50	0.02447	49.332	24.666	774.67
F	1396.90	0.02593	46.914	23.457	700.58
F£/Gb	1479.96	0.02747	44.614	22.307	633.57

	OPEN END COR	COTKL	L1	L2
C	5.89	28.22	74.99	55.06
C£/Db	5.60	26.83	70.74	51.82
D	5.32	25.52	66.73	48.77
D£/Eb	5.06	24.27	62.95	45.89
E	4.82	23.08	59.38	43.18
F	4.58	21.95	56.01	40.64
F£/Gb	4.35	20.87	52.83	38.24

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	130.05	161.75	4.00	4.00	0.097924
C£/Db	122.56	152.67	4.00	4.00	0.091849
D	115.49	144.11	4.00	4.00	0.086260
D£/Eb	108.84	136.02	4.00	4.00	0.081120
E	102.56	128.38	4.00	4.00	0.076394
F	96.65	121.18	4.00	4.00	0.072053
F£/Gb	91.07	114.38	4.00	4.00	0.068067

Diameter halving on step 19.7	
Mouth ratic calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
F£/Gb	14.20	7.10	11.15	2.79	3.15
G	13.71	6.85	10.77	2.69	3.04
G£/Ab	13.23	6.62	10.39	2.60	2.93
A	12.78	6.39	10.03	2.51	2.83
A£/Bb	12.33	6.17	9.69	2.42	2.73
B	11.91	5.95	9.35	2.34	2.64

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	1046.49	0.01942	55.072	27.536	965.41
C£/Db	1108.72	0.02058	53.170	26.585	899.88
D	1174.65	0.02180	51.334	25.667	838.79
D£/Eb	1244.49	0.02310	49.561	24.780	781.85

E	1318.50	0.02447	47.849	23.924	728.77
F	1396.90	0.02593	46.196	23.098	679.30
F£/Gb	1479.96	0.02747	44.601	22.300	633.19

	OPEN END COR	COTKL	L1	L2
C	5.38	25.76	75.50	56.99
C£/Db	5.19	24.87	71.15	53.35
D	5.01	24.01	67.04	49.93
D£/Eb	4.84	23.18	63.17	46.72
E	4.67	22.38	59.52	43.71
F	4.51	21.61	56.08	40.89
F£/Gb	4.35	20.86	52.83	38.24

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	132.49	161.75	4.00	4.00	0.088001
C£/Db	124.50	152.67	4.00	4.00	0.083914
D	116.97	144.11	4.00	4.00	0.080152
D£/Eb	109.89	136.02	4.00	4.00	0.076698
E	103.24	128.38	4.00	4.00	0.073537
F	96.97	121.18	4.00	4.00	0.070655
F£/Gb	91.08	114.38	4.00	4.00	0.068040

Diameter halving on step 13.4	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	11.50	5.75	9.03	2.26	2.55
C£/Db	10.92	5.46	8.58	2.14	2.42
D	10.37	5.18	8.14	2.04	2.30
D£/Eb	9.84	4.92	7.73	1.93	2.18
E	9.35	4.67	7.34	1.84	2.07
F	8.87	4.44	6.97	1.74	1.97
F£/Gb	8.43	4.21	6.62	1.65	1.87
G	8.00	4.00	6.28	1.57	1.77

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	2092.97	0.03884	36.128	18.064	415.48
C£/Db	2217.43	0.04115	34.303	17.152	374.55
D	2349.28	0.04360	32.570	16.285	337.66
D£/Eb	2488.98	0.04619	30.924	15.462	304.41
E	2636.98	0.04894	29.362	14.681	274.42
F	2793.79	0.05185	27.879	13.939	247.40
F£/Gb	2959.91	0.05493	26.470	13.235	223.03
G	3135.92	0.05820	25.133	12.566	201.06

OPEN END COR	COTKL	L1	L2

C	3.53	16.90	36.91	25.48
C£/Db	3.35	16.05	34.82	23.99
D	3.18	15.24	32.85	22.58
D£/Eb	3.02	14.47	30.99	21.25
E	2.87	13.74	29.23	20.00
F	2.72	13.04	27.57	18.83
F£/Gb	2.58	12.38	26.01	17.72
G	2.45	11.76	24.54	16.68

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	62.40	80.88	4.00	4.00	0.057373
C£/Db	58.81	76.34	4.00	4.00	0.054940
D	55.43	72.05	4.00	4.00	0.052724
D£/Eb	52.24	68.01	4.00	4.00	0.050707
E	49.23	64.19	4.00	4.00	0.048874
F	46.40	60.59	4.00	4.00	0.047212
F£/Gb	43.73	57.19	4.00	4.00	0.045707
G	41.21	53.98	4.00	4.00	0.044348

Great Fifteenth 2

Diameter halving on step	14.4
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	50.50	25.25	39.66	9.92	11.19
C£/Db	48.12	24.06	37.79	9.45	10.66
D	45.85	22.93	36.01	9.00	10.16
D£/Eb	43.69	21.85	34.32	8.58	9.68
E	41.63	20.82	32.70	8.17	9.22
F	39.67	19.84	31.16	7.79	8.79
F£/Gb	37.80	18.90	29.69	7.42	8.38
G	36.02	18.01	28.29	7.07	7.98
G£/Ab	34.32	17.16	26.96	6.74	7.60
A	32.71	16.35	25.69	6.42	7.25
A£/Bb	31.16	15.58	24.48	6.12	6.90
B	29.70	14.85	23.32	5.83	6.58

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	261.62	0.00486	158.650	79.325	8011.84
C£/Db	277.18	0.00514	151.174	75.587	7274.56
D	293.66	0.00545	144.051	72.025	6605.12
D£/Eb	311.12	0.00577	137.263	68.631	5997.28
E	329.62	0.00612	130.794	65.397	5445.38
F	349.22	0.00648	124.631	62.315	4944.27
F£/Gb	369.99	0.00687	118.758	59.379	4489.27
G	391.99	0.00728	113.162	56.581	4076.14
G£/Ab	415.30	0.00771	107.829	53.915	3701.04

A	439.99	0.00817	102.748	51.374	3360.45
A£/Bb	466.16	0.00865	97.906	48.953	3051.20
B	493.87	0.00917	93.293	46.646	2770.41

	OPEN END COR	COTKL	L1	L2
C	15.49	74.22	308.02	252.28
C£/Db	14.76	70.72	290.60	237.53
D	14.06	67.39	274.15	223.63
D£/Eb	13.40	64.21	258.64	210.55
E	12.77	61.18	244.00	198.22
F	12.17	58.30	230.19	186.62
F£/Gb	11.59	55.55	217.16	175.68
G	11.05	52.94	204.87	165.39
G£/Ab	10.53	50.44	193.27	155.69
A	10.03	48.06	182.33	146.56
A£/Bb	9.56	45.80	172.01	137.96
B	9.11	43.64	162.27	129.86

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	560.30	647.02	4.00	4.00	0.443057
C£/Db	528.12	610.70	4.00	4.00	0.410725
D	497.79	576.43	4.00	4.00	0.380805
D£/Eb	469.19	544.07	4.00	4.00	0.353119
E	442.23	513.54	4.00	4.00	0.327500
F	416.81	484.71	4.00	4.00	0.303796
F£/Gb	392.85	457.51	4.00	4.00	0.281865
G	370.26	431.83	4.00	4.00	0.261575
G£/Ab	348.96	407.59	4.00	4.00	0.242805
A	328.89	384.72	4.00	4.00	0.225443
A£/Bb	309.96	363.13	4.00	4.00	0.209383
B	292.12	342.74	4.00	4.00	0.194530

Diameter halving on step 18.4	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	28.30	14.15	22.23	5.56	6.27
C£/Db	27.25	13.63	21.40	5.35	6.04
D	26.24	13.12	20.61	5.15	5.81
D£/Eb	25.27	12.64	19.85	4.96	5.60
E	24.34	12.17	19.11	4.78	5.39
F	23.44	11.72	18.41	4.60	5.19
F£/Gb	22.57	11.28	17.73	4.43	5.00
G	21.73	10.87	17.07	4.27	4.82
G£/Ab	20.93	10.46	16.44	4.11	4.64
A	20.16	10.08	15.83	3.96	4.47
A£/Bb	19.41	9.70	15.24	3.81	4.30
B	18.69	9.35	14.68	3.67	4.14

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	523.25	0.00971	88.907	44.454	2516.07
C£/Db	554.36	0.01029	85.617	42.808	2333.28
D	587.33	0.01090	82.448	41.224	2163.77
D£/Eb	622.25	0.01155	79.397	39.698	2006.57
E	659.25	0.01224	76.458	38.229	1860.79
F	698.46	0.01296	73.628	36.814	1725.60
F£/Gb	739.99	0.01373	70.903	35.452	1600.24
G	783.99	0.01455	68.279	34.140	1483.98
G£/Ab	830.61	0.01542	65.752	32.876	1376.17
A	880.00	0.01633	63.319	31.659	1276.19
A£/Bb	932.33	0.01730	60.975	30.488	1183.48
B	987.77	0.01833	58.719	29.359	1097.50

	OPEN END COR	COTKL	L1	L2
C	8.68	41.59	153.07	122.22
C£/Db	8.36	40.05	144.32	114.68
D	8.05	38.57	136.06	107.59
D£/Eb	7.75	37.14	128.27	100.93
E	7.46	35.77	120.92	94.67
F	7.19	34.44	113.99	88.78
F£/Gb	6.92	33.17	107.45	83.25
G	6.66	31.94	101.29	78.06
G£/Ab	6.42	30.76	95.48	73.17
A	6.18	29.62	90.00	68.59
A£/Bb	5.95	28.52	84.83	64.28
B	5.73	27.47	79.95	60.24

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	275.30	323.50	4.00	4.00	0.180816
C£/Db	259.00	305.35	4.00	4.00	0.169995
D	243.65	288.21	4.00	4.00	0.159908
D£/Eb	229.20	272.03	4.00	4.00	0.150509
E	215.59	256.76	4.00	4.00	0.141758
F	202.77	242.35	4.00	4.00	0.133612
F£/Gb	190.71	228.75	4.00	4.00	0.126036
G	179.35	215.91	4.00	4.00	0.118995
G£/Ab	168.65	203.79	4.00	4.00	0.112456
A	158.59	192.36	4.00	4.00	0.106390
A£/Bb	149.11	181.56	4.00	4.00	0.100769
B	140.19	171.37	4.00	4.00	0.095565

Diameter halving on step 13.7	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	18.00	9.00	14.14	3.53	3.99
C£/Db	17.11	8.56	13.44	3.36	3.79

D	16.27	8.14	12.78	3.20	3.61
D£/Eb	15.47	7.74	12.15	3.04	3.43
E	14.71	7.36	11.55	2.89	3.26
F	13.99	6.99	10.99	2.75	3.10
F£/Gb	13.30	6.65	10.44	2.61	2.95

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	1046.49	0.01942	56.549	28.274	1017.88
C£/Db	1108.72	0.02058	53.767	26.883	920.19
D	1174.65	0.02180	51.122	25.561	831.88
D£/Eb	1244.49	0.02310	48.607	24.303	752.04
E	1318.50	0.02447	46.215	23.108	679.86
F	1396.90	0.02593	43.942	21.971	614.62
F£/Gb	1479.96	0.02747	41.780	20.890	555.63

	OPEN END COR	COTKL	L1	L2
C	5.52	26.45	75.36	56.44
C£/Db	5.25	25.15	71.09	53.13
D	4.99	23.91	67.06	50.01
D£/Eb	4.74	22.74	63.26	47.07
E	4.51	21.62	59.68	44.31
F	4.29	20.56	56.30	41.70
F£/Gb	4.08	19.54	53.11	39.25

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	131.80	161.75	4.00	4.00	0.090762
C£/Db	124.22	152.67	4.00	4.00	0.085030
D	117.07	144.11	4.00	4.00	0.079755
D£/Eb	110.34	136.02	4.00	4.00	0.074901
E	103.99	128.38	4.00	4.00	0.070438
F	98.00	121.18	4.00	4.00	0.066336
F£/Gb	92.36	114.38	4.00	4.00	0.062567

Diameter halving on step 19.1	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
F£/Gb	13.30	6.65	10.44	2.61	2.95
G	12.83	6.41	10.07	2.52	2.84
G£/Ab	12.37	6.18	9.71	2.43	2.74
A	11.93	5.96	9.37	2.34	2.64
A£/Bb	11.50	5.75	9.03	2.26	2.55
B	11.09	5.55	8.71	2.18	2.46

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
F£/Gb	1479.96	0.02747	41.779	20.889	555.60

G	1567.97	0.02910	40.291	20.146	516.74
G£/Ab	1661.20	0.03083	38.857	19.428	480.60
A	1759.99	0.03266	37.474	18.737	446.99
A£/Bb	1864.64	0.03461	36.139	18.070	415.73
B	1975.52	0.03666	34.853	17.426	386.65

	OPEN END COR	COTKL	L1	L2
F£/Gb	4.08	19.54	53.11	39.25
G	3.93	18.85	50.05	36.74
G£/Ab	3.79	18.18	47.16	34.38
A	3.66	17.53	44.43	32.17
A£/Bb	3.53	16.91	41.86	30.09
B	3.40	16.30	39.44	28.15

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
F£/Gb	92.36	114.38	4.00	4.00	0.062565
G	86.78	107.96	4.00	4.00	0.060203
G£/Ab	81.54	101.90	4.00	4.00	0.058069
A	76.60	96.18	4.00	4.00	0.056151
A£/Bb	71.96	90.78	4.00	4.00	0.054442
B	67.59	85.69	4.00	4.00	0.052931

Diameter halving on step 13.7	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	10.70	5.35	8.40	2.10	2.37
C£/Db	10.17	5.09	7.99	2.00	2.25
D	9.67	4.84	7.60	1.90	2.14
D£/Eb	9.19	4.60	7.22	1.81	2.04
E	8.74	4.37	6.87	1.72	1.94
F	8.31	4.15	6.53	1.63	1.84
F£/Gb	7.90	3.95	6.20	1.55	1.75

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	20.92	0.00039	33.615	16.808	359.68
C£/Db	22.16	0.00041	31.958	15.979	325.09
D	23.48	0.00044	30.382	15.191	293.83
D£/Eb	24.88	0.00046	28.884	14.442	265.57
E	26.36	0.00049	27.460	13.730	240.03
F	27.92	0.00052	26.107	13.053	216.94
F£/Gb	29.59	0.00055	24.819	12.410	196.08

	OPEN END COR	COTKL	L1	L2
C	3.28	15.72	4042.44	4029.99
C£/Db	3.12	14.95	3815.53	3803.70

D	2.97	14.21	3601.36	3590.11
D£/Eb	2.82	13.51	3399.21	3388.51
E	2.68	12.85	3208.40	3198.24
F	2.55	12.21	3028.31	3018.65
F£/Gb	2.42	11.61	2858.32	2849.14

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATICS	QUAL FAC
C	8072.43	8091.43	4.00	4.00	0.327516
C£/Db	7619.23	7637.29	4.00	4.00	0.302505
D	7191.46	7208.64	4.00	4.00	0.279404
D£/Eb	6787.72	6804.05	4.00	4.00	0.258068
E	6406.64	6422.17	4.00	4.00	0.238360
F	6046.95	6061.72	4.00	4.00	0.220158
F£/Gb	5707.46	5721.49	4.00	4.00	0.203346

Diameter halving on step 21.3	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
F£/Gb	7.90	3.95	6.20	1.55	1.75
G	7.65	3.82	6.01	1.50	1.69
G£/Ab	7.40	3.70	5.81	1.45	1.64
A	7.16	3.58	5.63	1.41	1.59
A£/Bb	6.94	3.47	5.45	1.36	1.54
B	6.71	3.36	5.27	1.32	1.49

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
F£/Gb	2959.91	0.05493	24.814	12.407	196.00
G	3135.92	0.05820	24.021	12.010	183.66
G£/Ab	3322.39	0.06166	23.252	11.626	172.10
A	3519.95	0.06533	22.508	11.254	161.26
A£/Bb	3729.26	0.06921	21.788	10.894	151.11
B	3951.02	0.07333	21.091	10.546	141.60

	OPEN END COR	COTKL	L1	L2
F£/Gb	2.42	11.61	26.17	18.26
G	2.34	11.24	24.64	17.04
G£/Ab	2.27	10.88	23.20	15.89
A	2.20	10.53	21.85	14.82
A£/Bb	2.13	10.19	20.57	13.82
B	2.06	9.87	19.36	12.88

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
F£/Gb	44.43	57.19	4.00	4.00	0.041106
G	41.68	53.98	4.00	4.00	0.041106
G£/Ab	39.10	50.95	4.00	4.00	0.041252

A	36.67	48.09	4.00	4.00	0.041544
A£/Bb	34.39	45.39	4.00	4.00	0.041982
B	32.24	42.84	4.00	4.00	0.042569

Diameter halving on step 42.6	
Mouth ratio calculated as	4.00000
Ratio of mouth width:diameter	4.00000
Temperature in degrees K	285.14990
Speed of sound (m per sec)	338.54562
Eccentricity of ellipse (e)	0.9682
Elliptic function K(e)	0.892
K(e)/0.89	1.002

	DIAMETER	RADIUS(R2)	MOUTH WIDTH	MOUTH HEIGHT	RADIUS(R1)
C	6.50	3.25	5.11	1.28	1.44
C£/Db	6.40	3.20	5.02	1.26	1.42
D	6.29	3.15	4.94	1.24	1.39
D£/Eb	6.19	3.10	4.86	1.22	1.37
E	6.09	3.05	4.78	1.20	1.35
F	5.99	3.00	4.71	1.18	1.33
F£/Gb	5.90	2.95	4.63	1.16	1.31
G	5.80	2.90	4.56	1.14	1.29

	FREQUENCY	WAVE NUMB	PLATE WIDTH	PLWTH/2	X-SECT AREA
C	4185.92	0.07769	20.420	10.210	132.73
C£/Db	4434.83	0.08231	20.091	10.045	128.48
D	4698.54	0.08720	19.766	9.883	124.36
D£/Eb	4977.93	0.09239	19.447	9.724	120.38
E	5273.94	0.09788	19.133	9.567	116.52
F	5587.54	0.10370	18.824	9.412	112.79
F£/Gb	5919.80	0.10987	18.520	9.260	109.18
G	6271.81	0.11640	18.221	9.111	105.68

	OPEN END COR	COTKL	L1	L2
C	1.99	9.55	18.23	12.00
C£/Db	1.96	9.40	17.12	11.09
D	1.93	9.25	16.08	10.23
D£/Eb	1.90	9.10	15.10	9.44
E	1.87	8.95	14.18	8.70
F	1.84	8.81	13.31	8.01
F£/Gb	1.81	8.66	12.49	7.37
G	1.78	8.52	11.72	6.78

	COMP. LENGTH	EFF. LENGTH	M/W RATIOS	M /W/C RATIOS	QUAL FAC
C	30.23	40.44	4.00	4.00	0.043319
C£/Db	28.21	38.17	4.00	4.00	0.045592
D	26.32	36.03	4.00	4.00	0.048190
D£/Eb	24.54	34.00	4.00	4.00	0.051146
E	22.88	32.10	4.00	4.00	0.054492
F	21.32	30.29	4.00	4.00	0.058267
F£/Gb	19.86	28.59	4.00	4.00	0.062515
G	18.50	26.99	4.00	4.00	0.067283

Bédos-type scales

Pedal Principal 16

	DIAMETER	MOUTH-WIDTH	MOUTH-HEIGHT
1	250.000	196.350	49.087
2	240.403	188.812	47.203
3	229.000	179.856	44.964
4	220.468	173.155	43.289
5	210.333	165.195	41.299
6	202.750	159.240	39.810
7	195.552	153.586	38.396
8	187.000	146.869	36.717
9	180.602	141.844	35.461
10	173.000	135.874	33.969
11	167.313	131.407	32.852
12	160.555	126.100	31.525
13	155.500	122.129	30.532
14	148.645	116.745	29.186
15	140.500	110.348	27.587
16	134.406	105.562	26.391
17	127.167	99.876	24.969
18	121.750	95.622	23.906
19	116.608	91.584	22.896
20	110.500	86.786	21.697
21	105.930	83.197	20.799
22	100.500	78.933	19.733
23	96.438	75.742	18.935
24	91.611	71.951	17.988
25	88.000	69.115	17.279
26	84.959	66.727	16.682
27	81.347	63.890	15.972
28	78.644	61.767	15.442
29	75.433	59.245	14.811
30	73.030	57.358	14.339

Pedal Octave 8

	DIAMETER	MOUTH-WIDTH	MOUTH-HEIGHT
1	147.000	115.454	28.863
2	142.075	111.585	27.896
3	136.222	106.989	26.747
4	131.844	103.550	25.887
5	126.642	99.464	24.866
6	122.750	96.408	24.102
7	119.056	93.506	23.377
8	114.667	90.059	22.515
9	111.383	87.480	21.870
10	107.482	84.416	21.104
11	104.563	82.123	20.531
12	101.095	79.399	19.850
13	98.500	77.362	19.340
14	94.062	73.876	18.469

15	88.789	69.735	17.434
16	84.844	66.636	16.659
17	80.157	62.955	15.739
18	76.650	60.201	15.050
19	73.321	57.586	14.397
20	69.367	54.480	13.620
21	66.408	52.157	13.039
22	62.893	49.396	12.349
23	60.263	47.330	11.833
24	57.138	44.876	11.219
25	54.800	43.040	10.760
26	52.433	41.181	10.295
27	49.620	38.971	9.743
28	47.516	37.319	9.330
29	45.016	35.355	8.839
30	43.145	33.886	8.472

Great Principal 8'

	DIAMETER	MOUTH-WIDTH	MOUTH-HEIGHT
1	138.000	108.385	27.096
2	132.719	104.237	26.059
3	126.444	99.309	24.827
4	121.750	95.622	23.906
5	116.173	91.242	22.810
6	112.000	87.965	21.991
7	108.039	84.854	21.213
8	103.333	81.158	20.289
9	99.813	78.393	19.598
10	95.630	75.107	18.777
11	92.500	72.649	18.162
12	88.782	69.729	17.432
13	86.000	67.544	16.886
14	83.207	65.351	16.338
15	79.889	62.745	15.686
16	77.406	60.795	15.199
17	74.457	58.478	14.620
18	72.250	56.745	14.186
19	70.155	55.100	13.775
20	67.667	53.145	13.286
21	65.805	51.683	12.921
22	63.593	49.946	12.486
23	61.938	48.646	12.161
24	59.971	47.101	11.775
25	58.500	45.946	11.486
26	55.860	43.872	10.968
27	52.722	41.408	10.352
28	50.375	39.564	9.891
29	47.586	37.374	9.344
30	45.500	35.736	8.934
31	43.520	34.180	8.545
32	41.167	32.332	8.083
33	39.406	30.950	7.737
34	37.315	29.307	7.327

35	35.750	28.078	7.019
36	33.891	26.618	6.654
37	32.500	25.525	6.381
38	31.363	24.632	6.158
39	30.011	23.571	5.893
40	29.000	22.777	5.694
41	27.799	21.833	5.458
42	26.900	21.127	5.282
43	26.047	20.457	5.114
44	25.033	19.661	4.915
45	24.275	19.066	4.766
46	23.374	18.358	4.589
47	22.700	17.829	4.457
48	21.899	17.200	4.300
49	21.300	16.729	4.182
50	20.349	15.982	3.996
51	19.220	15.095	3.774
52	18.375	14.432	3.608
53	17.371	13.643	3.411
54	16.620	13.053	3.263
55	15.907	12.493	3.123
56	15.060	11.828	2.957

Great Octave 4

	DIAMETER	MOUTH-WIDTH	MOUTH-HEIGHT
1	78.500	61.654	15.413
2	75.809	59.540	14.885
3	72.611	57.029	14.257
4	70.219	55.150	13.787
5	67.377	52.917	13.229
6	65.250	51.247	12.812
7	63.231	49.662	12.415
8	60.833	47.778	11.945
9	59.039	46.369	11.592
10	56.908	44.695	11.174
11	55.313	43.442	10.861
12	53.418	41.954	10.489
13	52.000	40.841	10.210
14	49.705	39.038	9.760
15	46.978	36.896	9.224
16	44.937	35.294	8.823
17	42.514	33.390	8.348
18	40.700	31.966	7.991
19	38.979	30.614	7.653
20	36.933	29.007	7.252
21	35.403	27.806	6.951
22	33.585	26.378	6.594
23	32.225	25.309	6.327
24	30.609	24.040	6.010
25	29.400	23.091	5.773
26	28.364	22.277	5.569
27	27.133	21.310	5.328

28	26.212	20.587	5.147
29	25.119	19.728	4.932
30	24.300	19.085	4.771
31	23.523	18.475	4.619
32	22.600	17.750	4.437
33	21.909	17.208	4.302
34	21.089	16.563	4.141
35	20.475	16.081	4.020
36	19.746	15.508	3.877
37	19.200	15.080	3.770
38	18.418	14.465	3.616
39	17.489	13.736	3.434
40	16.794	13.190	3.297
41	15.968	12.541	3.135
42	15.350	12.056	3.014
43	14.763	11.595	2.899
44	14.067	11.048	2.762
45	13.545	10.638	2.660
46	12.926	10.152	2.538
47	12.463	9.788	2.447
48	11.912	9.356	2.339
49	11.500	9.032	2.258
50	10.959	8.607	2.152
51	10.316	8.102	2.025
52	9.834	7.724	1.931
53	9.263	7.275	1.819
54	8.835	6.939	1.735
55	8.429	6.620	1.655
56	7.947	6.241	1.560

Great Fifteenth 2

	DIAMETER	MOUTH-WIDTH	MOUTH-HEIGHT
1	50.500	39.663	9.916
2	48.245	37.892	9.473
3	45.567	35.788	8.947
4	43.562	34.214	8.553
5	41.181	32.344	8.086
6	39.400	30.945	7.736
7	37.709	29.617	7.404
8	35.700	28.039	7.010
9	34.197	26.858	6.715
10	32.411	25.456	6.364
11	31.075	24.406	6.102
12	29.488	23.160	5.790
13	28.300	22.227	5.557
14	27.254	21.405	5.351
15	26.011	20.429	5.107
16	25.081	19.699	4.925
17	23.977	18.831	4.708
18	23.150	18.182	4.545
19	22.365	17.566	4.391
20	21.433	16.834	4.208
21	20.736	16.286	4.071

22	19.907	15.635	3.909
23	19.287	15.148	3.787
24	18.551	14.570	3.642
25	18.000	14.137	3.534
26	17.259	13.555	3.389
27	16.378	12.863	3.216
28	15.719	12.345	3.086
29	14.936	11.731	2.933
30	14.350	11.270	2.818
31	13.794	10.834	2.708
32	13.133	10.315	2.579
33	12.639	9.927	2.482
34	12.052	9.466	2.366
35	11.613	9.120	2.280
36	11.091	8.710	2.178
37	10.700	8.404	2.101
38	10.273	8.069	2.017
39	9.767	7.671	1.918
40	9.387	7.373	1.843
41	8.937	7.019	1.755
42	8.600	6.754	1.689
43	8.280	6.503	1.626
44	7.900	6.205	1.551
45	7.616	5.981	1.495
46	7.278	5.716	1.429
47	7.025	5.517	1.379
48	6.725	5.282	1.320
49	6.500	5.105	1.276
50	6.383	5.013	1.253
51	6.244	4.904	1.226
52	6.141	4.823	1.206
53	6.017	4.726	1.181
54	5.925	4.653	1.163
55	5.837	4.585	1.146
56	5.733	4.503	1.126

FOOTNOTES

INTRODUCTION

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CHAPTER ONE

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3. Charles Ferguson in the extensive essay to the Eng. trans of F.Bédos de Celles, *op. cit.*, p xxi.
4. Bédos de Celles, *op. cit.*, p.27.
5. *loc. cit.*
6. *loc. cit.*
7. *ibid.*, p.28.
8. *loc. cit.*
9. Sorge, Georg Andreas: *Die gehem gehalte Kunst von Mensuration von Orgel -Pfeiffen* (M.S. c.1760); edited and English translation by C.O.Bleyle as *The Secretly kept art of the Scaling of Organ pipes*,(Buren. 1978) p.2.
10. Bédos de Celles, *op. cit.*, p.xxxvii (preface by Bédos to Part II)
11. Sorge, G.A: *op. cit.*, p.1.
12. Bédos de Celles: *op. cit.*, p.28.
13. *ibid.* p.29
14. *loc. cit.*
15. *ibid.* p.30
16. *ibid.* p.31
17. *ibid.* p.21
18. See note 9
19. Bleyle gives the date of publication of Sorge's *...zuverglaessige Anweisung Claviere und Orgeln behörig zu temperiren und zu stimmen* as 1788; Buelow, *Sorge*, in S.Sadie (ed.), *The N G D of M M* (1980), vol. 17, p.538 gives the publication details as 'Leipzig and Lobenstein, 1758'.
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21. Quoted in Bleyle's essay with the translation of G.A. Sorge's *The Secretly kept art of the Scaling of Organ pipes*, p.100.
22. Sorge, G.A:*Anweisung zur Rational-Rechnung*,(Lobenstein, 1749), p.30
23. Bleyle, Carl O:*Georg Andreas Sorge: An 18th Century proponent of logarithmic scaling for organ-pipes*. *Organ Year Book*, 6, 1975, p.54.
24. Buelow, G.J: Mizler von Kolof, in S.Sadie (ed.), *The N G D of M M* (1980), vol. 12, p.373.
25. Bleyle's essay with the translation of G.A.Sorge's *The Secretly kept art of the Scaling of Organ pipes*, p.95.

26. *loc. cit.*
27. Johann Georg Meckenheuser(b.1666), cathedral and court organist of Quedlinburg, in his *Untersuchung der sogenannten aller neuste Temperatur* (Quedlinburg, 1727), had shown how to divide the octave logarithmically as well as by root extraction. Johann Christoph Breitfield (?-?) had used logarithms to calculate Telemann's interval system which divided the octave into 55 parts.
28. Bleyle, C.O: *op. cit.*, p.98.
29. Marenholz, Christhard: *Die Berechnung der Orgelpfeifenmensuren*,(Kassel, 1937/R1968); English translation by A.Williams: *The Calculation of organ pipe scales*,(Oxford,1975);page numbers refer to the English translation: p.65.
30. *ibid.*
31. 1000 *Scruples* = 1 *Fuss*. 100 *Scruples* = 1 *Zoll*, 10 *Scruples* = 1. *Gran* 1 *Fuss* is not easy to interpret in metric units. Sorge made no indication as to which 'foot' he was using: the Russian (1 *Fuss* = 286.5mm) or the Saxon (283.19mm). The *Fuss* which Sorge uses for 8' C of a Principal tuned in *Chorton* with a circumference of 277 *Scrupel* is approximately 280.3mm. This information is from Bleyle, *op. cit.*, p.65, note 11.
32. Sorge, G.A: *The Secretly kept art of the Scaling of Organ pipes*, pp.7-9.
33. *idem.*, *Der in der Rechen-und Messkunst....*(Lobenstein, 1773). Material in brackets in this table is compiled by Bleyle, the rest by the author.
34. *idem.*, *The Secretly kept art of the Scaling of Organ pipes*, p.11.
35. *ibid.* p.12
36. *ibid.* p.22
37. *idem: Anweisung zur Rational-Rechnung*,(Lobenstein, 1749) Lesson 11, pp.263-293
38. *idem.*, *The Secretly kept art of the Scaling of Organ pipes*. p.29.
39. Ingerslev, F. & Frobenius, W: Some measurements of the End-Corrections and Acoustic Spectra of cylindrical open Flue Organ Pipes, in *Transactions of the Danish Academy of Sciences (A.T.S)* 1947, No.1.
40. Sorge, G.A: *op. cit.*, p.1.
41. *ibid.* p.30.
42. Cavaillé-coll's length formula does a similar thing.
43. Sorge, G.A: *op. cit.*, p.31.
44. *ibid.*, p.34.
45. Bleyle, C, essay in G.A.Sorge: *op. cit.*, p.78.
46. Mersenne, Marin: *Harmonie Universelle*, *The Books on Instruments*, Trans.Roger E. Chapman (Nijhoff, The Hague, 1957), p. 418.
47. *ibid.*, p. 424.
48. See the Bibliography for works by Toepfer.
49. The Rensch Slide-Rule (invented by Richard Rensch) or the *Rechenschieber fur Orgelpfeiffen* is a German organ-building tool which has not been accepted to any real extent in this country. This is partly because the Germans see their craft as developing from a technical view-point and the British builders view scientific innovation with contempt, preferring 'traditional'

(nineteenth century) methods of construction which are, in fact, hand-me-down methodologies from Toepfer (although no-one really studied Toepfer's work, only the work of continental builders like Cavaillé-Coll and the Schulze firm who were intimately aquainted with Toepfer's work) and thus based on scientific and mathematical theory. The English organ-building scene is at once a paradox and a tautology from this point of view.

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51. Schlick, A: *Spiegel der Orgelmacher und Organisten*, (Speyer, 1511/R 1959; ed. and Eng. trans. E.B.Barber, Buren, 1980).
52. Virdung, S: *Musica getutscht*,(Basle, 1511; ed. and Eng. trans. C.Meyer, 1980)
53. Praetorius, W: *Syntagma musicum*, ii, (Wolfenbuttel 1918, 2/1619/R 1958 and 1980; Eng.trans. H. Blumenfeld 1949 and D. Crookes, 1986)
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55. Bendeler, J.P: *Organopoeia*, (Frankfurt am Main, 1690/R1972, 2/1739)
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67. Sumner, W.L: The Schulze Family, *The Organ*, vol. XXXVII, (145), July 1954, p.9.
68. Wilke, J: Über der Erfidung der Rohrwerke mit durchschlagenden Zungen,(25, 1823), and J.Wilke & F.Kaupfmann, Über die Crescendo und Diminuendo-Zuge an Orgeln,(25, 1823, p113f), both in *Allgemeine musikalische Zeitung*.
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CHAPTER TWO

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12. *ibid.*, p. 248.
13. *ibid.*, p. 249.
14. *ibid.*, p. 248.
15. *ibid.*, p. 249.
16. *ibid.*, p. 250-1.
17. See note 11 for the full title.
18. This term is used by Erwin R. Jacobi: in Sadie, Stanley

(ed.), *The NGD of MM*, vol. 17, p. 44.

19. Williams, Peter: *A New History of the Organ from the Greeks to the Present Day, (Faber & Faber, London, 1980). chapter 24, p. 192.*

20. *ibid.*, p. 189.

21. *loc.cit.*

20. Gurlitt, Wilibald (ed.), *Bericht über die Freiburger Tagung für deutsche Orgelkunst (Ausberg, 1926); Walcker, Oscar: Zur geschichte der Orgelmensuren und Bedeutung für die kunst des Orgelbaues, pp. 43-48; Jahnn, Hans Henny: Gesichtspunkte für die wakl Zweckmässiger pfeifenmensuren. pp. 50-58.*

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25. *loc. cit.*, Williams appears to be copying Clutton's statement in The Schnitger Organ at Steinkirchen, *The Organ*, vol. 30 (119), January 1951, p.108, Clutton appears to have copied it from Sumner, Arp Schnitger and his Organs, *The Organ*, vol. 17 (67), January 1938, p. 145. Sumner, however, being a mathematician presumably saw the difference between the constant, fixed-variable and free-variable scaling methods and explains in his article Toepfer's notions. Sumner was writing at at time when the term $1:\sqrt{8}$ was probably not linked quite so strongly with Toepfer's geometric series as it is today, and has been since Marenholz made his study of pipe scaling methods, (published in 1938). The term is now used to denote specifically the use of a geometric proportion between a reference pipe and a pipe of serial number *n* as in Robinson's equations. Schnitger could not possibly have halved his *prinzipals* in a constant proportion as Williams implies, as it can only have been done in the style of Bédos's charts, which are not logarithmic.

26. The organ presently at Cappel was built by Arp Schnitger between 1679 and 1680 and installed at St. Johannis-Kloster, Hamburg. Since 1816 it has been in Cappel, near Bremenhaven. A full list opus list of Schnitger's organs is in Pape, Uwe: Arp Schnitger, *ISO Information* 5, February 1971, pp. 375-374.

27. Williams, Peter: *The European Organ*, p. 115.

28. The scales of Schnitger were apparently gathered together sometime before the Second World War. There seems to be some reluctance to pin-point their present location, possibly because the scales may have been gathered with some political motivation in mind. This, however is only hear-say and may contain no truthfulness at all.

29. A list of Dr. Gustav Fock's publications is contained in Pape, *op. cit.*, p. 374.

30. Reinburg, Peggy Kelly: *Arp Schnitger, Organ Builder*, (Bloomington, Indiana University Press, 1982) pp. 131-145.

31. Downes, Ralph: *Baroque Tricks*, (Positif Press, Oxford, 1983), p. 132.

32. Reinburg, *op. cit.*, p. 140.
33. Sumner, William Leslie, Arp Schnitger and his Organs. *The Organ*, vol. 17 (67), January 1938, p. 145.
34. No precise scalings are given in Gurlitt, Wilibald, (ed.), *Bericht über...*, p. 44, but the following scale ratios are given for 8' and 4' stops of the *Hauptwerk* at St. Jakobi, Hamburg:

	C - c	c - c1	c1 - c2	c2 - c3
Prinzipal 8'	1:1.87	1:1.67	1:1.61	1:1.87
Oktav 4'	1:1.84	1:1.73	1:1.61	1:1.41

35. The figures above show a similarity with the exception of the last octaves.
36. Douglass, Fenner: *Cavaillé-Coll and the Musicians*, (Sunbury Press, Raleigh, 1980) p.2.
37. *ibid.*, p. 9.
38. Sumner, William Leslie: Aristide Cavaillé-Coll and the Organ at St. Denis Abbey, *The Organ*, vol. 26 (101), July 1946, p. 22.
39. Charles Spackmann Barker was British, although his action-type never achieved any popularity in this country but found favour with Parisian organ-builders.
40. Douglass, F: *op.cit.*, pp. 163-4.
41. Audsley, G.A: *op. cit.*, title of chapter 15, pp. 1-12.
42. Cavaillé-Coll, Aristide: *Complete Theoretical Works*, ed. and annotated by G. Huybens, (Fritz Knuf, Buren, 1979).
43. Douglass, F: *op.cit.*, introduction (Letters IV, 2341, November 12, 1852).
44. *ibid.*, p. 42, see appendix A.
45. *ibid.*, p. 160.
46. *ibid.*, p. 324. (Letters IV, 2341, December 11, 1852).
47. *loc. cit.*
48. Eugene Marca evidently wrote to Cavaillé-Coll, desirous of studying organ-building with him on a visit to Paris in 1852. It was his intention to complete his theoretical and practical studies with him.
49. Douglass, F: *op.cit.*, pp. 299-300, (Letters III, 1932, February 7, 1851).
50. *ibid.*, p. 421. (Devis I, 139, November 20, 1844, Cathedral of Nantes).
51. *ibid.*, p. 422.
52. *ibid.*, p. 146 (Letters I, 801, February 26, 1842).
53. *ibid.*, p. 355 (Letters V, 3116, January 11, 1856, to Mr. F.W. Sourek, Organ-builder in Cologne).
54. *ibid.*, p. 334 (Letters IV, 2527, September 10, 1853, to Mr. Schonnagel, Organist of *La Trinité*, Marseilles.).
55. *ibid.*, p. 406. (Devis I, 139, May 15, 1836, St. Laurent a Paris)
56. Isaacs, Alan (ed.): *Dictionary of Physics*, (London, 1986), p. 106.
57. Two examples spring to mind: the organ at Rawtenstall Parish Church, built by the Hill company in the late 19th century has a Cavaillé-Coll-type console, and Besses o'th' Barn United Reformed Church has a three manual Wadsworth organ dating from various periods in the late 19th-century, has a storm effects pedal, two sets of string stops (Swell

and Choir), harmonic flutes, unweighted tongues on most reed stops, lieblich flutes, a IV-rank Great mixture plus 2′and 2 2/3′ diapasons, a selection of Great 8′ stops after the Cavaillé-Coll fonds combination, and couplers arranged in the Cavaillé-Coll manner, but above the Swell keyboard, a deta ched, pneumatic console, and a dummy rückpositiv organ behind which is the console.

58. *Tableau en provenance des ateliers de Cavaillé-Coll*, quoted by Klotz, H in Cavaillé-Coll, Aristide, in Sadie, Stanley (ed.), *The NGD of MM*, vol. 4, p. 20.
59. Contained in Cavaillé-Coll, Aristide: *Complete Theoretical Works*, ed. and annotated by G. Huybens, (Fritz Knuf, Buren, 1979).
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61. *ibid.*, p. 16.
62. Austin Niland in Clutton, Cecil and Niland, Austin: *The British Organ* gives the date of Edmund Schulze's death as 1879. William Sumner in The Schulze Family, *The Organ* vol. 37 (145), July 1957, (part 1), gives the dates of Johann Andreas Schulze as 1753-1806. The dates quotes in the text for members of the Schulze Family are taken from Hans Klotz's article Schulze, in Sadie, Stanley (ed.), *The NGD of MM*, vol. 16, p. 823.
63. Ahllin, Max: the preface to *Die Theorie und Praxis des Orgelbaues*, (Leipzig, 1888), p. vii.
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65. Sumner, William Leslie: The Schulze Family, *The Organ* vol. 37 (146), October 1957, p. 96.
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67. *loc. cit.*
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70. Hird, Richard: *The 'Father' Willis organ, St. Luke's church, Winterton Hopsital (formerly Durham County Asylum) nr. Sedgefield, Co. Durham* (private publication), p. 2.
71. Henry Willis, 1821-1901.
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74. *loc. cit*
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76. *ibid.*, p. 26.
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79. Norman, Herbert: The Normans 1860-1920, *JBIOS* 10, 1986, p. 59.
80. Sumner, William Leslie: The Schulze Family, *The Organ* vol. 37 (146), October 1957, p. 99.
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82. Bonavia-Hunt, Noel A: *op. cit.*, p 18.
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89. *ibid.*, p. 8.
90. Godfrey, Arthur: The Late James Jepson Binns and his Work in the Hartlepools, *The Organ*, vol. 32, (127), January 1953, p. 127.
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92. *ibid.*, p. 7.
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94. The Organ at Beverley Minster was rebuilt by Hill in 1885, its Great Organ large open diapason then having a diameter at C of 152.4mm blown on a pressure of 76.2mm of water. Arthur Harrison added a larger open diapason (also available on the Solo organ) with a scale at C of 165.1mm on a wind-pressure of 158.8mm of water. See Clutton, Cecil: The Organ at Beverley Minster, *The Organ*, vol. 33 (129), July 1953, pp. 12-20.
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100. Hopkins and Rimbault quote the following scales:
St. Paul's Cathedral 'Schmidt'[sic], largest open diapason C=6"[152.4mm]
Temple Church, London 'corresponding pipe' 5, 1/3" [135.5mm].
Temple Church FFF [FF], 7" [177.8mm]
'largest of the two original CCC [CC] or 16-feet Pipes, at St. Paul's, is a little under 10" across [approx. 254mm]','The CC [C] pipe he increased from 6 to 8 inches [152.4mm to 203.2mm], his GG [this must be a misprint, the authors must mean GGG, now designated GG] to 11 [279.4mm] and his FFF [FF] from 7 to 12 [to 304.8mm]; that is, to 2 inches beyond Smith's scales for the 16-feet Pipe. Avery and England...reduced the scale again for the Bass of the Metal Diapasons.', *op. cit.*, pp. 281-282.
101. *ibid.*, p. 282.
102. The specification is in Hopkins, Edward John and Rimbault, Edward F: *op. cit.*, p. 542.
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107. *ibid.*, p. 543.
108. Sumner, William Leslie: *op. cit.*, p. 96.
109. He certainly visited them, see specification numbers 42.

43, 51, 52, 56, 61, 63, 64, 70, 73, in Hopkins, Edward John and Rimbault, Edward F: *op. cit.*
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121.Sumner, William Leslie: *op. cit.*, p. 100.
122.Bonavia-Hunt, Noel A: *Studies in Organ Tone*, (London, 1915), second edition, p. 20.
123.Godfrey, Arthur: The Late James Jepson Binns and his Work in the Hartlepools, *The Organ*, vol. 32, (127), January 1953, p. 125.
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125.Norman, Herbert: The Normans 1860-1920, *JBIOS* 10, 1986, p. 53.
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127.*ibid.* p. 57.
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CHAPTER THREE

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JBIOS	*The Journal of The British Institite of Organ Studies*
JISO	*The Journal of The International Society of Organ-Builders*
MT	*The Musical Times*
The NGD of MI	*The New Grove Dictionary of Musical Instruments*
The NGD of MM	*The New Grove Dictionary of Music and Musicians*
OLF	*The Organ Literature Foundation*
ORGBLDR	*The Organbuilder*
ORGYBK	*The Organ Yearbook*
OUP	*Oxford University Press*
PM	*The Philosophical Magazine*
PMA	*The Proceedings of The Musical Association*
PR	*The Physical Review*

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